

# DOMESTIC MICA

BY G. RICHARDS GWINN

\* \* \* \* \* Information Circular 7617



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G. Richards Gwinn<sup>1/</sup>

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## INTRODUCTION

"Mica" is a group name for a number of orthosilicates of aluminum with magnesium, ferrous iron, and the alkalies. They are characterized by their high reflection and a basal cleavage so well developed that they can be split into exceedingly thin laminae, which are more or less tough, elastic, and transparent, according to variety. Barium, manganese, lithium, chromium, titanium, boron, and ferric iron occur in some varieties. Eight distinct species of true mica, which appear in the following table, are recognized by mineralogists, but only the first five are of commercial importance.

| <u>Species</u>    | <u>General Formula</u>                |
|-------------------|---------------------------------------|
| Muscovite.....    | $H_2KAl_3(SiO_4)_3$                   |
| Phlogopite.....   | $[H,K,(MgF)]_3 Mg_3Al(SiO_4)_3$       |
| Biotite.....      | $(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$  |
| Lepidolite.....   | $K,Li Al(OH,F)_2 Al(SiO_3)_3$         |
| Roscoelite.....   | $H_8K(Mg,Fe)(Al,V)_4(SiO_3)_{12}$     |
| Paragonite.....   | $H_2NaAl_3(SiO_4)_3$                  |
| Zinnwaldite.....  | $(K,Li)_3 FeAl_3 Si_5O_{16}(OH,F)_2$  |
| Lepidomelane..... | $HK_2F_3^{II}Fe_6^{III}Al_3(SiO_4)_9$ |

These formulas are of a general nature, as all species of mica vary considerably in composition, giving rise to numerous varieties. The formulas show, however, the approximate composition of the typical species and indicate why, in accordance with the prominence of the elements, muscovite is commonly called potash mica; biotite, iron mica; lepidolite, lithium mica; and paragonite, sodium mica. The micas crystallize in the monoclinic system but are pseudo-hexagonal in habit, and distinct terminated crystals are rare. All species of mica are optically biaxial with varying axial angle, commonly show the same forms, and frequently intercrystallize in parallel position. Thin sheets of muscovite containing areas of biotite, or vice versa, are common; muscovite and lepidolite may crystallize in this same pattern.

In ancient times mica was used for decoration, and in modern times, before the use of electricity, it was used chiefly for glazing in stove windows, doors, and in lanterns. Large quantities also were utilized in lamp chimneys and lampshades. Only clear sheets with perfect cleavage were suitable. With the advent and rapid growth of the electrical industry, the major use of sheet mica shifted to this industry. Scrap mica obtained from mine dumps, sheet mica-processing shops, and deposits containing only small or foliated crystals serve as raw material for mica grinders. Ground mica is used in roofing material, wallpaper, paints, lubricants, as a filler in rubber products, and for many decorative purposes.

Of the five commercial micas, muscovite, phlogopite, and biotite are used solely because of their physical properties. Muscovite or potash mica is the most important mica of commerce and is the only one mined extensively in the United States.

The domestic mica industry began in 1803 with the opening of the Ruggles mine in Grafton County, New Hampshire. Soon afterward other deposits were opened in this region; New Hampshire became the leading producer until shortly after the Civil War, when large-scale production began in North Carolina, and mining in New Hampshire declined. North Carolina is now the leading producer. Until recently, substantial quantities also have been obtained from New Hampshire, and mica has also been produced intermittently in Virginia, South Dakota, New Mexico, Georgia, Connecticut, Idaho, and Maine.

The abnormal demands for mica during World War II brought many changes in the domestic industry. New records for annual production of sheet, punch, and scrap were set. Improvements in the technology of mining and milling brought advancements, particularly in prospecting for deposits and in trimming of the finished product. Because of the more complete trimming the quantity of finished product per pound of mica mined decreased, but the monetary return increased. However, in general the increase in value has not been enough to permit profitable competition with imported material.

New uses for ground mica were developed during the war, and although some of them were confined to wartime demands, most of them have a place in peacetime economy. Substitutes for sheet mica also were developed during this period, some of which are continuing in use as alternate materials. Mica, however, is still an essential component in the communication and electrical-insulation industries, but the number of places in which it is essential in these industries has been reduced permanently.

## MINERALOGY

### Muscovite

Muscovite usually occurs as tabular crystals, hexagonal or rhombic in outline, with prismatic faces more or less rough and striated horizontally. These crystals range in size from 5 to 6 feet in diameter, weighing 1 to 2 tons, to less than 1/16 inch across, aggregated in stellate, feathery, or globular forms, or they may be crypto-crystalline. Muscovite has an eminent basal cleavage as well as secondary cleavage, better described as parting planes, which cut the crystals at angles of 60° to 70° with the basic cleavage.

The parting planes may extend entirely through a crystal or only part of the way, either across the cleavage face or through the thickness of the crystal.

Thin laminae of muscovite are transparent, flexible, elastic, and usually colorless. Sheets 1/8 inch or more in thickness, however, usually show a distinct color - some shade of gray, brown, red, yellow, or green. The color, owing to variations in the chemical composition, classifies the mica as "ruby," "rum," "green," "smoked" etc. Zonal coloration with a definite relation to crystal structure is found occasionally. Muscovite ranges in hardness from

2 to 2.5, has a specific gravity of 2.76 to 3, a colorless streak, and commonly a vitreous luster. The index of refraction ranges from 1.56 to 1.59. It is optically negative and normally has an axial angle of 50° to 70°. Usually it is feebly pleochroic and has a rather strong double refraction. It is insoluble in acids and may be heated to 400°C. without change; at this temperature, however, it begins to give up minute quantities of its water of crystallization, and at 700° C. normal muscovite loses about 1/10 percent of its weight. As dehydration progresses, the mica swells, loses its transparency, and becomes brittle.

Sericite is a common modified form of muscovite. It is defined as a more or less altered variety of muscovite, or the name is sometimes applied to unaltered muscovite in aggregates of fine scales with a silky luster but without cleavage. It is also an alternation product of feldspar, kyanite, and many other aluminum silicates.

### Phlogopite

Phlogopite occurs in monoclinic crystals, which usually are irregular and tapering six-sided prisms that range in size from 4 feet in diameter to minute particles. Phlogopite also has perfect basal cleavage. Thin laminae are transparent to translucent and are also flexible and elastic. They often exhibit asterism in transmitted light owing to regularly arranged inclusions. Sheets 1/8 inch or more in thickness show some shade of yellow, brown, green, or almost black. Phlogopite has a pearly to submetallic luster on cleavage surfaces, with a coppery reflection.

The color of phlogopite often indicates its hardness, which ranges from 2.5 to 3, the darker kinds being harder than the light-colored ones. Its index of refraction ranges from 1.56 to 1.61, and it has a specific gravity of 2.74 to 2.95. Unlike muscovite, however, it decomposes in concentrated sulfuric acid, leaving thin, porous scales of silica. Phlogopite also has a greater resistance to heat than muscovite, being unaffected up to 800° C., although the power factor of some phlogopites is increased by this temperature (8).<sup>2/</sup>

### Biotite

Biotite occurs in embedded crystals, in disseminated scales, and in lamellar masses. Crystals are pseudo-hexagonal, like those of muscovite. Thin laminae are translucent, and sheets 1/8 inch or more in thickness are dark brown or black. Thin sheets are less flexible and elastic than muscovite or phlogopite.

The hardness of biotite ranges from 2.5 to 3, the index of refraction from 1.54 to 1.63, and specific gravity from 2.75 to 2.95. Like phlogopite, it decomposes in concentrated sulfuric acid. Its high iron content reduces its di-electric strength. Biotite has a distinct cleavage parallel to the base, but this cleavage does not always carry across the width of the crystal. Splitting qualities are therefore poor in comparison with muscovite and phlogopite.

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<sup>2/</sup> Numbers in parentheses refer to items in the bibliography at the end of this paper.

## OCCURRENCE

Mica is of common occurrence in igneous, sedimentary, and metamorphic rocks. Muscovite and biotite are the most common of the micas, occurring abundantly usually as small scales in many granites, gneisses, schists, and other related rocks. Some rocks, however, are composed almost entirely of mica. Large crystals of muscovite and biotite are found in pegmatites, and large crystals of phlogopite are found in serpentinized limestones, dolomites, and pyroxenic rocks.

A few schists exceptionally rich in muscovite are milled for their mica content, and a considerable quantity of fine muscovite is recovered as a by-product from kaolin deposits. Muscovite sheet, however, is the most important mica of commerce, and all marketable deposits of this material are found in pegmatites. Therefore, the occurrence and composition of this type of rock will be summarized briefly.

## PEGMATITES

The word "pegmatite" was coined by R. J. Hauy, a French mineralogist and physicist, in the early years of the 19th century as a descriptive term applied to rocks with a graphic texture. Gradually, the use of the term was extended to include all types of exceptionally coarse igneous rocks, whether graphic or not (11).

Pegmatites recently have been defined as "rocks with coarsely and unevenly crystallized and segregated minerals occurring as dikes, veins, or metamorphic masses formed from the igneous solutions of a freezing magma or from the combination of the solutions with previously existing minerals (7)."

They range in size from dikes and veins 1 mile or more long and up to 300 feet wide to thin stringers an inch across and a few inches long, or they may be lenses, oval masses, or pipes as much as several hundred feet across. The principal minerals in these bodies are the plagioclase feldspars (oligoclase and albite), microcline (a potash feldspar), quartz, and the micas (muscovite and biotite). However, many other minerals may be present. Forty-four different minerals have been found in the pegmatites of the Spruce Pine district of North Carolina. The relative proportions of the principal minerals vary not only in adjacent pegmatites but also in different parts of the same body.

## COMMERCIAL DEPOSITS

The commercial value of muscovite, phlogopite, and biotite mica depends primarily on a combination of physical properties (perfect cleavage, heat and electrical resistance, flexibility, and elasticity) rather than chemical composition. Thus, analyses of these micas are not included.

## Muscovite

Muscovite mica is distributed sporadically in pegmatites, and commercially valuable deposits are localized in shoots or pockets in granitic pegmatites in which the predominant feldspar is plagioclase, or in sections of pegmatites that consist mainly of quartz and plagioclase feldspar. The amount of recoverable mica ranges from 2 to 10 percent of the rock mined, averaging about 4 percent. The color of mica in any one shoot is fairly uniform, but if two or more shoots occur in the same pegmatite, the color in one may differ from that of the other. A rigid geologic classification of mica deposits is almost impossible, as each shoot or pocket differs in detail from most others. A study of the geologic reports on the mica mines and areas in the United States, Brazil, Canada, Africa, and India shows, however, that certain generalizations may be made based on the mode of distribution of the mica in the pegmatite. Perhaps the best description of this distribution is contained in a recent report by E. N. Cameron, D. M. Larrabee, and others, of the U. S. Geological Survey (2). This report describes only the mica mines in the New England States, but it is believed that the types mentioned are applicable to mica mines throughout the world. Five major types are recognized. They are wall-zone, core-margin, pocket, vein, and disseminated. In general, the types are distinct, but gradations occur, and thus two classifications of complex deposits and special types are added.

Wall-zone deposits are those in which the books of muscovite are concentrated in a layer of the pegmatite near the wall or contact of the mass with the surrounding country rock. Hanging-wall deposits are the most numerous, but some footwall deposits have been found. In a few cases both footwall and hanging wall deposits are found in the same pegmatite. The essential minerals of these deposits are quartz, plagioclase feldspars (albite or oligoclase), and muscovite.

Core-margin deposits occur in narrow zones in or close to massive bodies of quartz, or quartz and feldspar, that commonly occur near the center of the pegmatite. The mica shoots or mica-bearing zones are composed essentially of quartz, plagioclase, and muscovite and usually occur on both sides of the core.

Pocket deposits are common in large pegmatites. The books of mica are restricted primarily to masses of coarse-textured quartz, perthite (quartz and microcline feldspar), or cleavelandite and quartz. The pockets, for the most part, are small, and the over-all quantity of sheet mica in this type of deposit therefore is usually quite restricted.

Vein deposits. - These consist of thin, tabular bodies ranging in width from 6 inches to 10 feet and from 15 to about 200 feet long, composed primarily of quartz, perthite, plagioclase, and muscovite, with minor quantities of tourmaline, garnet, and other accessory minerals. This type of deposit is sometimes found in pegmatites that contain pocket deposits. Records of commercial production from vein deposits are few, because they rarely sustain economic mining.

Disseminated deposits are those in which mica books are scattered, without any apparent orientation, throughout the width of the pegmatite. Occasionally, however, slight orientation or segregations of the mica may be discernable along the walls or near the core. The deposits are formed primarily of mixtures of coarse-grained quartz, plagioclase, and potash feldspar, and muscovite mica; the minor constituents are usually garnet, beryl, tourmaline, and other typical pegmatite minerals.

Complex deposits. - These deposits occur when two or more of the foregoing types of deposits are found in the same pegmatite. They cannot be classed as an independent type and must be considered in terms of their component parts.

Special types. - In this classification are the sheet-muscovite deposits that do not belong to the types described above. They include deposits found in schistose wall rocks of pegmatites in which the mica books have been formed largely by enrichment of the wall rocks by pegmatite solutions. Included also are deposits in which lathlike intergrowths of muscovite and biotite transect graphic granite, and deposits that are associated very closely with potash feldspar.

#### Phlogopite

Phlogopite mica is not produced commercially in the United States, although small deposits are known to exist in various localities, notably in St. Lawrence County, New York, and Morris and Warren Counties, New Jersey.

#### Biotite

Biotite-mica mining is confined to two North Carolina deposits, one at Hanging Rock and the other at Tampa Mountain northeast of Spruce Pine. They consist of layers of biotite schist in pegmatite. The biotite schist is believed to have been formed by the alteration of a hornblende gneiss by hydrothermal solutions derived from the alaskite magma which underlies the region (17).

### GEOGRAPHICAL DISTRIBUTION OF DEPOSITS

This discussion of domestic mica resources is confined almost entirely to known muscovite deposits or muscovite-bearing pegmatities. The principal areas in the United States that contain such deposits are shown in figure 1.

The largest district extends from central Virginia through the western Carolinas, northern Georgia, and east-central Alabama. This is by far the largest area and probably contains the largest reserves of commercial mica. Second in importance is a relatively small region in southwestern New Hampshire. The large production from this comparatively small region is due to the higher percentage of marketable sheet mica obtained per mine and the ease with which the pegmatities can be exploited, as they are not covered with as much residual soil as those in the southeastern region.

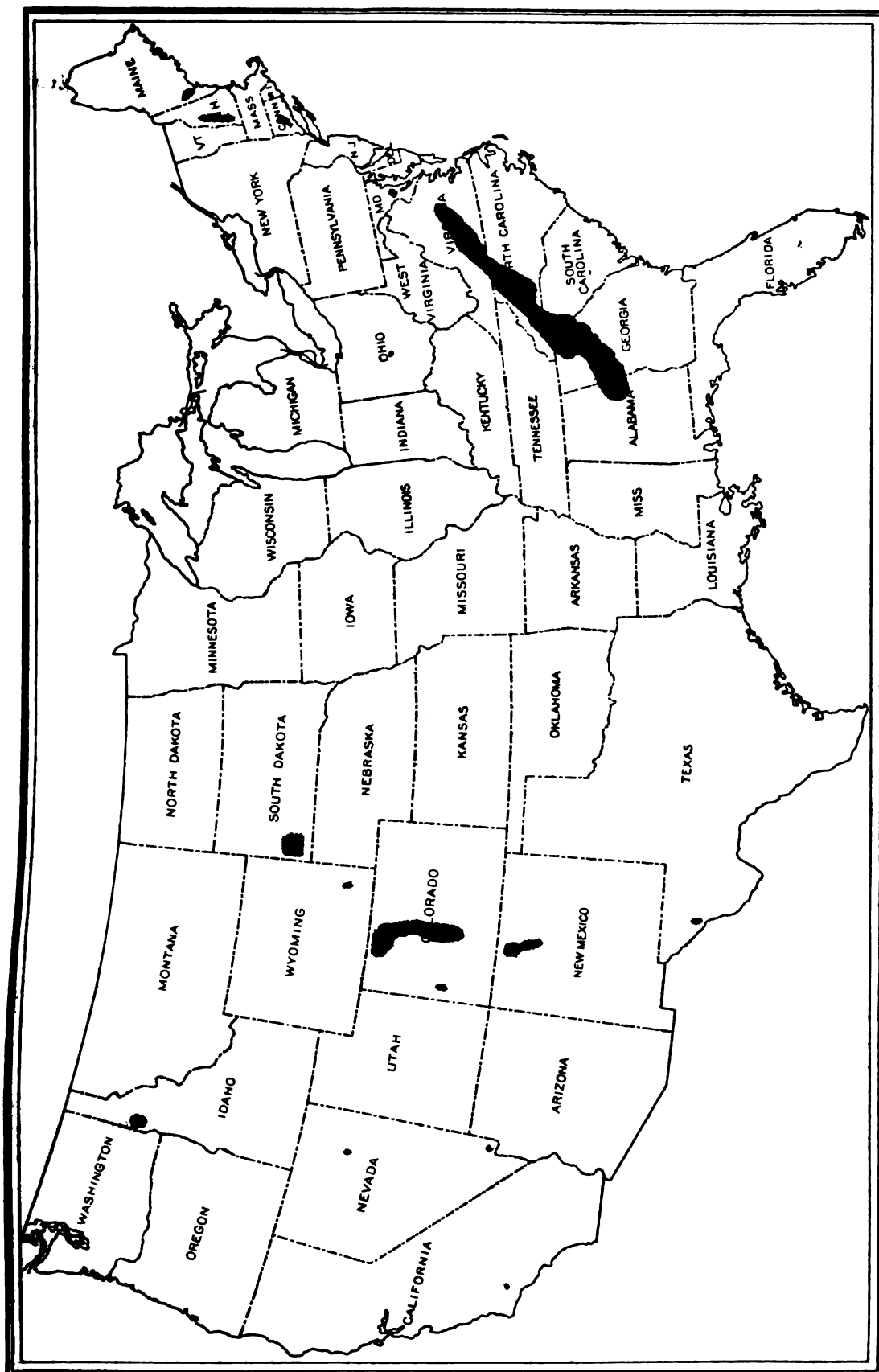


Figure 1. - Location of principal muscovite deposits of the United States.

Next in importance are the pegmatites in the Custer and Keystone regions of the Black Hills, South Dakota. The advantages of this district are the comparatively close spacing of the pegmatites in a small area and the abundance of associated minerals such as spodumene, amblygonite, lepidolite and columbite, occurring in commercial quantities. An area in northern New Mexico has been developed to some extent, but, because most of the sheet muscovite is distorted or ruled, which makes it marketable only as scrap, it is improbable that New Mexico will become an important producer of sheet mica.

A small district in northwestern Idaho has been a sporadic producer of sheet muscovite of good quality. During World War II production from this region reached considerable proportions and Idaho became the sixth largest mica producing State in 1944. The peacetime operation of mica mines in this region, however, is seriously handicapped because of the long distance from markets.

Small areas in southwestern Maine, central Connecticut, and Massachusetts contain deposits of commercial grade. The pegmatites that skirt the eastern slope of the Front Range of the Rockies from Wyoming southward through the central part of Colorado yield small quantities of sheet mica, but the bulk of the mica from this area is of scrap quality. Some mica has been mined in Maryland, Pennsylvania, Texas, Nevada, and California; none of these States, however, has been an important producer.

#### DESCRIPTION OF DEPOSITS, BY STATES

##### Alabama

The mica deposits in Alabama are confined to the east-central part of the State. The best deposits are in Randolph, Clay, and Tallapoosa Counties, and smaller deposits have been worked in Lee and Coosa Counties. The mica-bearing rocks in this State form the southern end of the great southeastern mica belt that extends northeast to central Virginia. The pegmatites and the enclosing schists and gneisses are deeply weathered. Most of the sheet mica in Alabama is "A mica," the recoverable sheet coming from the center of the A.

##### Colorado

Although there are numerous mica-bearing pegmatites in Colorado, the quantity of sheet mica recovered has been small. This is due chiefly to earth movement after the formation of the mica that distorted the sheets, and also to an imperfect cleavage that does not continue across the entire crystal, thus preventing the recovery of sheet mica of commercial quality. The bulk of the mica in this State, therefore, is suitable only for grinding.

##### Connecticut

In this State, mica has been produced in Middlesex, Hartford, New Haven, Fairfield, and Litchfield Counties. Most of it has originated in the first two counties named. Although production is confined to a relatively small area, this State was among the five leading producers from 1935 to 1945.

## Georgia

Mica-bearing pegmatites are found in about 20 counties in this State, most of which are in the Piedmont Plateau, although some of them are in the northeast corner of the State in the Blue-Ridge Province. Production has come chiefly from Cherokee, Hall, Hart, Monroe, Lamar, Pickens, Upson, and Rabun Counties. As in North Carolina, the deposits are associated chiefly with the Carolina and Roan gneisses. The rocks in the mica-bearing areas have been deeply weathered, and dewatering became a serious problem in many of the mines. The outcrops of many of the pegmatites are marked by kaolin-containing quartz boulders and clay-stained mica books. Georgia mica is of good grade, but, because of the surface clay staining, deep weathering of the rocks, and the proximity to the surface of the underground water level, which brings water into many of the mines and prospects, little development or mica mining was done in this State prior to World War II. However, in 1943 Georgia became the fourth largest producer of sheet mica in the United States.

## Idaho

Mica-bearing pegmatites have been found in several Idaho counties, but commercial production of mica has been reported only from those in Latah County. The deposits in that county that lie near Avon, about 25 miles northeast of Moscow, occur in pegmatites that have intruded pre-Cambrian schists and gneisses. Production was first reported in 1888 from the Muscovite and Maybe mines. Operations were continuous until 1918, when the mines were closed, and no production was reported until the Government subsidized prices of World War II made it profitable to operate. The mica is a good grade of light ruby muscovite, and sheets as large as 12 by 18 inches have been recovered.

## Maine

Most of the mica produced in Maine is obtained as a byproduct of feldspar mining in Oxford, Sagadahoc, Cumberland, and Androscoggin Counties. The bulk of the material mined is marketable only as scrap mica, but some excellent sheet has been obtained from a few operations.

## New Hampshire

The principal mica deposits in this State are in the southwestern area in Cheshire, Grafton, and Sullivan Counties. Small quantities also have been obtained from deposits in Merrimack, Strafford, and Coos Counties.

The rocks into which the mica-bearing pegmatites have been intruded are schists and gneisses. The country is glaciated, and many of the pegmatites are therefore more exposed than those in the Southern States, although in the valleys they may be covered to great depths with glacial gravels. The most productive deposits in New Hampshire are of the "wall-zone" type. The percentage of ruby and white mica recovered in this State is higher than in North Carolina. The iron content of New Hampshire mica is lower than in the Southern States.

Adverse weather in winter has handicapped mining, but with the knowledge gained during the war years and the advances in prospecting methods it is possible that this State will retain its position as a major mica producer.

### New Mexico

The principal mica deposits in this State are west and southwest of Petaca in Rio Arriba County and in the Glorieta Mountains in San Miguel County. Much of the sheet mica in these two regions is ruled, distorted, A, or tangle sheet and marketable only for scrap. A small percentage will yield good punch and small sheet. Because of the high proportion of material marketable only as scrap and small size sheet, which command a low return, plus the relative inaccessibility of the deposits, production in this State is small.

### North Carolina

The mica deposits in North Carolina have been grouped by Sterrett into three main belts - the Cowee-Black Mountain, the Blue Ridge, and the Piedmont (2). The Cowee-Black Mountain belt lies west of the Blue Ridge and roughly parallels the western border of the State. It traverses Ashe, Watanga, Avery, Mitchell, Yancey, Buncombe, Jackson, and Macon Counties. The Blue Ridge belt follows the Blue Ridge Mountains through the State and includes mines in Macon, Jackson, Transylvania, McDowell, Caldwell, and Wilkes Counties. The Piedmont belt includes mines in Rutherford, Burke, Cleveland, Gaston, Lincoln, Catawabe, and Stokes Counties.

The mica-bearing pegmatites of this State have been intruded at all angles into the highly metamorphosed Carolina and Roan gneisses. These gneisses, probably of Archean age, have been altered extensively by folding, faulting, and great pressure, until it is difficult to determine whether the original formations were igneous or sedimentary. Younger granites, volcanic rocks, diabase, and sedimentary deposits also occur in parts of the region. Some of the mica deposits are on the sides of steep hillside outcroppings or under thin soil cover, and others are on gentle slopes of valleys under a deep cover of residual clay. Drainage on the whole is a serious problem only in the Piedmont belt, where elevation and slope are slight. Many mines in this region must be pumped. North Carolina is the largest mica-producing State, but a large part of the sheet mica recovered is green, some of which, because of its high power factor, has only a limited use in the electrical industry. The relatively high iron content of North Carolina mica prevents its use as ground mica utilized in the manufacture of glass-bonded mica insulation.

On the basis of large mines that were in operation from 1941 through 1944, the three mica-producing belts of this State may be subdivided into four districts. These districts, listed in order of importance, follow:

1. Spruce Pine
2. Sylva-Franklin
3. Shelby
4. Rockingham-Stokes

The largest number of green-mica mines are in the Spruce Pine district, where they constitute approximately 65 percent of the major mines. About 25 percent of the mines in the Franklin Sylva area, 25 percent in the Shelby area, and 50 percent in the Rockingham-Stokes district produce green mica. Most of the ground mica produced in the United States also comes from the Spruce Pine district.

### South Dakota

The mica deposits in this State are in the southern part of the Black Hills, near Keystone, about 6 miles east-northeast of Harney Peak, and also in the vicinity of Custer, about 8 miles south-southwest of this mountain. The mica-bearing pegmatites, for the most part, have been intruded conformably into Archean gneisses, in which alteration has been extensive (5). Sheet mica has been produced intermittently from deposits in this State since 1907. From 1919 to 1939, the bulk of the production consisted of scrap mica produced as a byproduct of feldspar mining. From 1941 through 1944, this State ranked third as a producer of sheet mica, and in 1945 it ranked second.

### Virginia

The principal mica deposits in this State are in Amelia, Henry, Hanover, Franklin, and Powhatan Counties. The mica-bearing pegmatites occur largely in pre-Cambrian gneisses and schists of the Piedmont plateau. Production began in 1867, about the same time that the first deposits in North Carolina were being opened. The mines near Hewlett, in Hanover County, were the first to be operated (25). Production was intermittent until 1916, but since that date some mica has been produced each year. A few of the mica deposits, notably those in the vicinity of Amelia Courthouse, contain a wide variety of minerals, which make the occurrence of special interest to the mineralogist.

## SHEET MICA

### Physical Characteristics (21)

Sheet mica as it comes from the mine is commonly in rough blocks ranging from a few inches to as much as 5 or 6 feet in maximum diameter. These blocks usually have ragged outlines and no plane boundaries, although they occasionally show well-developed crystal faces of hexagonal or rhombic prisms. Owing to structural characteristics, inclusions, and color, the rough crystals or books have certain physical peculiarities, to which miners and mica dealers apply descriptive terms. Thus, on the basis of their structural imperfections, micas are designated as "ruled," "ribboned," "A," "hair-lined," "herringbone," "fish-bone," "horsetail," "feather," "wedge," and "tangle-sheet." Inclusions have given rise to such terms as "black-spotted," "heavy-stained," "red-stained," "clay-stained," etc. On the basis of color, micas are variously known as "rum," "rudy," "white," "smoky," "green," "light amber," and "silver-black."

## Structural Imperfections

The structural imperfections of rough mica crystals constitute the largest factor determining the yield of sheet mica.

Parting planes often develop in the mica books from strains or movements in the enclosing rock, splitting the mica sheets into narrow strips or ribbons. This ruling is sometimes so extensive that the ribbons are almost hairlike, and it may render large mica crystals, otherwise of excellent quality, fit only for scrap.

In "A" mica, two series of striations cross the sheets at an angle of about  $60^{\circ}$  with each other, forming a V. The third striation necessary to form the letter A is lacking, but this variety is nevertheless termed "A" mica. Sometimes the striations are evidently caused by wedge structure in the crystals and again by small ridges or folds in the sheets. If the striations are formed by wedging, only that portion between the A lines is usable as sheet mica; but if they are caused by folding, the mica may split across the folds and yield sheets of some value though not of first quality. Where the striation extend only in one direction the mica is known as "hair-line".

Striations apparently identical with those of "A" mica, but making angles of about  $120^{\circ}$  with each other and joining at a center line or spine, give rise to a structure known as "fishbone," "herringbone," "horsetail," or "feather;" mica with such structure has no value except for grinding.

The crystals of wedge mica, as the name implies, are wedge-shaped and are thicker on one side than on the other. This structure is common in "A" and "fishbone" mica and is due to unequal development in width of the laminae forming the crystals, only some of which extend the entire width of the block.

"Tangle-sheet" is caused by the intergrowth of individual laminae, so that they split in some places but bind in others; apparently sound crystals are thus made nearly valueless.

The mica books may be badly distorted, buckled, or corrugated, conditions probably produced by earth movements coincident with or subsequent to their crystallization. In fact, perfectly flat mica is rare; a slight waviness may be detected in even the best grades by touch or by visible differences in the reflection of light from their surfaces.

Air bubbles between the laminae are not unusual. If these are large and confined only to certain planes within the block, they can be removed by splitting; in some instances, however, small bubbles are widely distributed between the folia, so that their removal is impossible. Sometimes these bubbles are microscopic and are so numerous as to form clouds in the mica. Bubbles probably are caused by strains in the mica while in the ground.

## Impurities

The most common impurities in mica are iron oxides, silica, and clay impregnating the crystals along their cleavage planes. The opportunity for infiltration of these impurities may have been afforded by opening of the cleavage planes through bending or distortion of the crystal by earth movements after their formation. Magnetite, perhaps the most prevalent inclusion, occurs as black spots and dendritic forms, which are sometimes arranged in patterns having a definite relation to the crystal structure, or they may be scattered irregularly through the sheets. Magnetite inclusions often alter to hematite or limonite, becoming red or brownish yellow.

In some localities, thin sheets of silica occurring as inclusions between the mica laminae interfere greatly with splitting of the mica. Some of these inclusions are heavy and occur in the form of wedges or lenses as much as a quarter of an inch thick.

Clay stains due to the infiltration of muddy water between the laminae are common impurities in mica. They occur only in mica coming from the zone of surface weathering. These impurities may be confined to certain planes only in a crystal, and thus may be removed by splitting.

Crystals of garnet and black tourmaline are common inclusions in mica. Although usually small, garnets up to three quarters of an inch in diameter and tourmaline crystals several inches long have been found embedded in the sheets. Crystals of biotite also are prevalent in the muscovite, or vice versa. Such intergrowths, although interesting from the standpoint of the mineralogist, render mica unfit for sheeting.

## Colors

Muscovite, biotite, and phlogopite are the micas of commerce. Muscovite is light-colored and, when split into sheets less than one-sixteenth of an inch, may be colorless and is called white mica. Sheets of one-sixteenth of an inch thickness are used to determine the color of any particular piece or shipment of muscovite. The colors reported are rum, ruby, smokey, green, and brown. Biotite, the iron mica, is dark, usually brown, brownish black, or green, and is opaque to translucent in all but thin sheets. Phlogopite, the magnesium mica, ranges in color from yellow through brown to black, or it may have a coppery appearance. Thin sheets of phlogopite are less transparent than muscovite owing to the presence of minute inclusions.

Ruby-colored muscovite is preferred by capacitor manufacturers because it has a low power factor and is easy to split, in contrast to green mica, which may be brittle and may have a high power factor.

The color standard for ruby mica prior to the 1941-45 period was based only upon the observation and judgment of mica inspectors. Because of the critical importance of mica in the war emergency, a study was made at the National Bureau of Standards to set up in fundamental terms a color standard for ruby mica that could be applied particularly to micas close to the border line between ruby and green. The report shows that judgment by visual

inspection alone is satisfactory for micas that are definitely ruby or green, but that the procedure outlined in this report may be of some assistance in determining border-line material (10).

### Preparation for Market (6)

Proper preparation of sheet mica for sale requires judgment in eliminating minor structural imperfections and inclusions as well as knowledge and experience in trimming, splitting, cutting, grading, and classification. Grading and classification of mica are means of delineating, within the limits of standard groups, an endless series of variations in size and quality. The poorest quality in one classification approximately equals the best of the next inferior classification; likewise, the largest size in one grade nearly equals the smallest size of the next larger grade.

Processes of preparation include (1) cobbing, (2) rifting or sheeting, (3) trimming, (4) grading by size, and (5) classifying as to quality. These are described briefly.

Cobbing. - Crystals or "books" of mica as taken from the mine are known as "mine-run," and ordinarily rock adheres to them. Cobbing is the process of removing the dirt and rock from the crystals and segregating the defective mica (scrap) from the crystals that will yield good block (cobbed mica).

Rifting. - Rifting is splitting the cobbed mica into sheets usually 10 to 125 mils thick. A single- or double-edged, 3-inch-blade, rifting knife generally is used in this operation, and its proper use involves considerable skill and experience. The products of rifting are (1) untrimmed block of mixed sizes, (2) punch and washer stock, and (3) scrap. Preparation of mica by properly trained rifters is extremely important, as inexperienced workers will at best fail to recover the maximum value from the crude books and at worst can render a product virtually unusable for anything but scrap.

Care should be exercised in rifting to avoid breaking or tearing laminations at each point where the knife is inserted in the rough book. Much potentially useful mica can be spoiled or reduced in value by careless or inexperienced rifting.

Trimming. - Trimming of rifted blocks to remove ragged and tangled edges may be accomplished by knife, shears, guillotine, or fingers.

In domestic practice, ragged edges are broken from the rifted block mica with the fingers (thumb trim) or are roughly trimmed with a knife so that very little usable mica is removed. The domestic practice is based upon the theory that the manufacturers can cut the largest pattern of specific quality from the rough-trimmed block and still have trimmings from which to produce smaller patterns of lower quality; but mica thus prepared is difficult to appraise properly, because the defective or unsound mica area is different in each piece. This results in a greater proportion of waste in fabricating thumb-trimmed mica as compared with knife-trimmed blocks, and its value per pound, therefore, is lower.

Knife trimming, however, produces a smaller quantity of uncut or unmanufactured mica and a larger percentage of scrap at the mine than thumb-trimmed.

To be of maximum value to consumer and producer, all sheet mica should be trimmed with beveled edges, and the total area of any piece of sheet mica offered for sale should not be greater than 2-1/2 times the area of the largest rectangle, free of cracks, reeves, or crossgrains, that can be cut from it.

Half trim mica is trimmed on two adjacent sides, with no cracks extending from the trimmed sides. Three-quarter trim is trimmed on all sides, with no cracks extending from two adjacent sides and no cracks extending into the pattern. Full trim mica is trimmed on all sides, with all cracks, reeves, and crossgrains removed.

Care should be exercised in handling and packing block mica, as the surfaces are easily scratched and the edges readily damaged by rough handling and improper packing. It should be packed securely in wooden cases and compressed to prevent shifting during shipping. The interior of the case should be free from projecting nails and rough surfaces.

Grading. - Domestic mica is graded upon the basis of the largest usable rectangle of specific quality that can be cut from the block, although the edges may be heavy-stained or otherwise defective. It is important that the sound areas only of each block be considered in determining its grade size. The sound area of specific quality within the grade rectangle must be free of cracks, pinholes, cross-grained areas, etc. Domestic grading as to size is as follows: The smallest circular size, designated as punch, is sheet mica, from which disks and washers at least 1 inch and not more than 2 inches in diameter may be punched. It must be virtually flat, although it may contain cracks and may be clear or stained. The sheet yielding washers 2 inches in diameter are called "circle mica." Then follow the rectangular sizes or combinations equal in area to 1-1/2 by 2 inches, 2 by 2 inches, 2 by 3 inches, 3 by 3 inches, 3 by 4 inches, 3 by 5 inches, 4 by 6 inches, 6 by 8 inches, 8 by 10 inches, and larger, known as "sheet mica." Figure 2 shows these grade sizes graphically. Each size includes the designated dimensions and all larger sizes up to the next grade. A sheet 4-1/2 by 7 inches would be classed as 4 by 6 inches.

Use of simplified grading chart. - The three concentric circles in figure 2 show the minimum area of small punch, punch, and circle, respectively. Place the mica so that the circle of the sound area is centered at 0 and observe the relation of the circles to this area. If it is larger than the smallest circle and smaller than the intermediate it is classed as "small punch;" if it is larger than the intermediate circle and smaller than the outer circle it is "punch," etc.

For rectangular or square blocks, place the mica so that the lower right corner of the sound area is at 0, the smaller dimension of the sound area extending along the vertical line and the larger dimension along the horizontal line. The largest rectangle on the chart that is completely within the

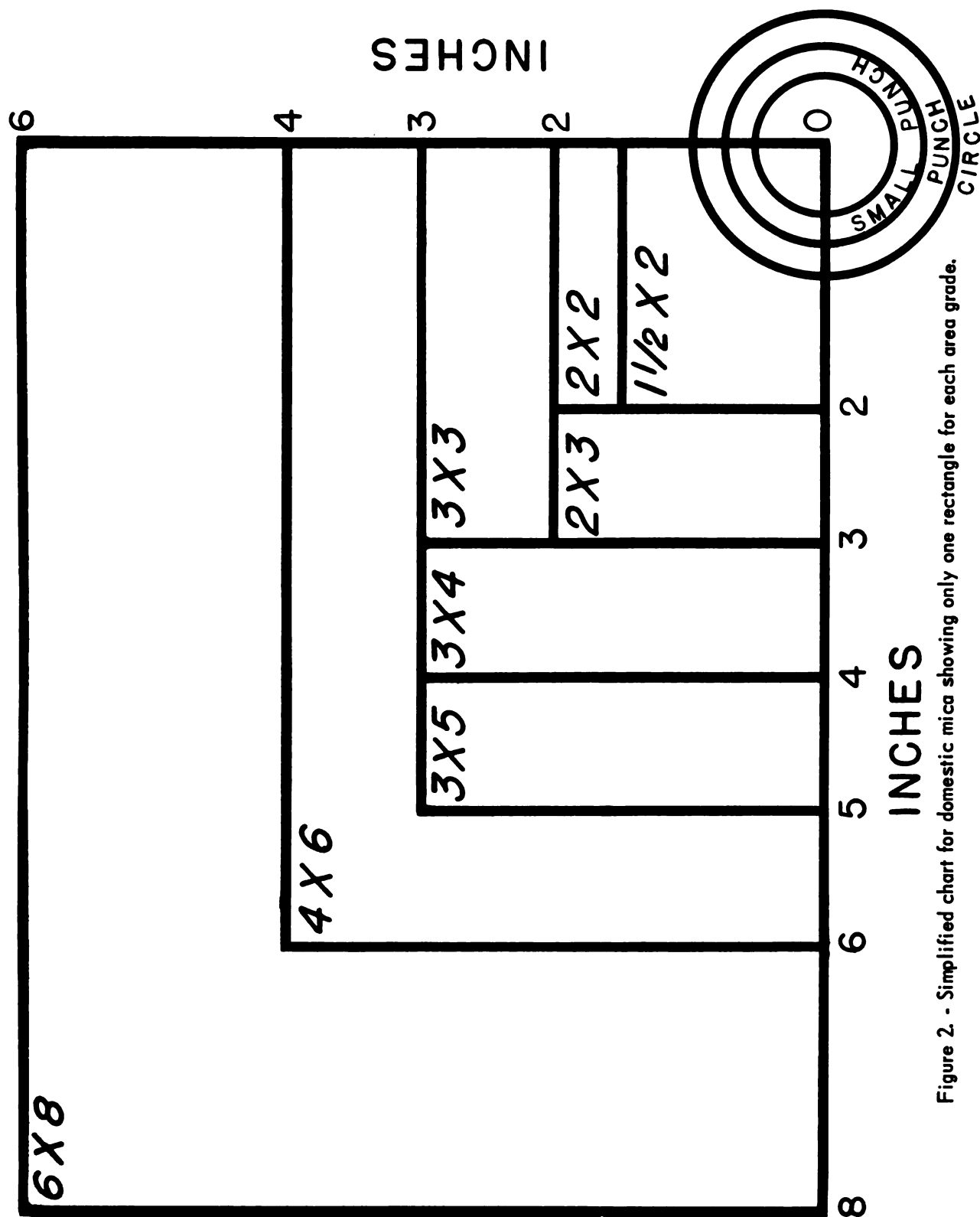


Figure 2. - Simplified chart for domestic mica showing only one rectangle for each area grade.

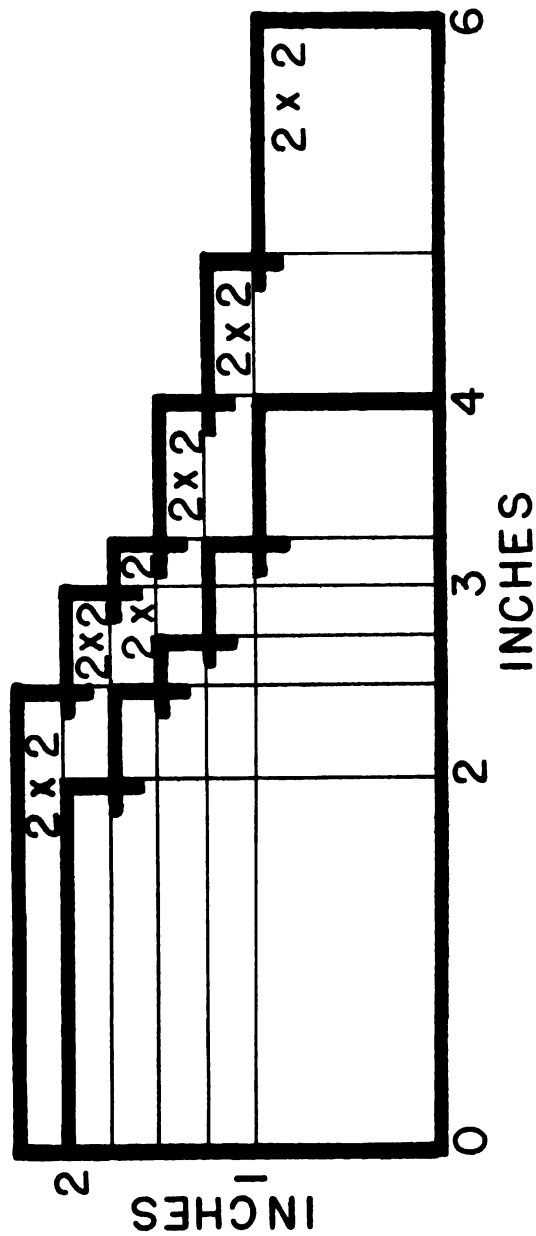


Figure 3. - Chart for grading 2- by 2-inch mica.

boundaries of the sound area indicates the grade size. Each grade size includes mica of the designated minimum dimensions and smaller than the next larger size. A block or sheet the usable area of which is 1-1/2 by 2-1/2 inches is classed as 1-1/2 by 2 inches. Sizes 8 by 8 inches and 8 by 10 inches and larger are not shown on this chart.

In many instances it will be well for the miner to prepare a grading chart suited to his specific needs. It must be remembered that the simplified chart shows only one dimension combination for each grade size. The minimum acceptable area for 2- by 2-inch sheets is 4 square inches, and the maximum is 6 square inches. The smallest or minimum dimension in this grade is 1 inch. Thus, a strip of mica 1 inch wide may range in length from 4 inches to 6 inches. The following tabulation shows the combinations of dimensions that may be used to construct a 2- by 2-inch grading chart. The series of rectangles with a common point at 0 outline the smallest acceptable and largest areas economical in the 2- by 2-inch grade.

| <u>Smallest or minimum</u><br><u>area (4 sq. in.), inches</u> | <u>Largest or maximum</u><br><u>area (6 sq. in.), inches</u> |
|---------------------------------------------------------------|--------------------------------------------------------------|
| 1 by 4                                                        | 1 by 6                                                       |
| 1-1/4 by 3-1/4                                                | 1-1/4 by 4-3/4                                               |
| 1-1/2 by 2-3/4                                                | 1-1/2 by 4                                                   |
| 1-3/4 by 2-1/2                                                | 1-3/4 by 3-1/4                                               |
| 2 by 2                                                        | 2 by 3                                                       |
|                                                               | 2-1/4 by 2-1/2                                               |

Actually, the dimensions in the column at the left in the preceding table outline the upper limit to the 1-1/2-by 2-inch grade and the lower limit of the 2- by 2-inch grade, whereas the column at the right is the upper limit of the 2- by 2-inch grade and the lower limit of the 2- by 3-inch grade. Figure 3 is constructed with the above dimensions and may be used to grade 2- by 2-inch sheets.

Domestic and Indian grading (by size), approximate comparison

| Usual<br>domestic grades | Area (in single rectangle),<br>sq. in. |                | Standard<br>Indian grades |
|--------------------------|----------------------------------------|----------------|---------------------------|
|                          | <u>Minimum</u>                         | <u>Maximum</u> |                           |
| Small punch.....         | 1                                      | 1-1/2          |                           |
| Punch.....               | 1-1/2                                  | 2-1/2          | No. 6                     |
| Circle.....              | 2-1/2                                  | 3              | No. 5-1/2                 |
| 1-1/2 by 2 inches .....  | 3                                      | 4              | { No. 5                   |
| 2 by 2 inches .....      | 4                                      | 6              |                           |
| 2 by 3 inches .....      | 6                                      | 9              | No. 4                     |
| 3 by 3 inches .....      | 9                                      | 12             | { No. 3                   |
| 3 by 4 inches .....      | 12                                     | 15             |                           |
| 3 by 5 inches .....      | 15                                     | 24             | No. 2                     |
| 4 by 6 inches .....      | 24                                     | 36             | No. 1                     |
|                          | 36                                     | 48             | No. 1A                    |
| 6 by 8 inches .....      | 48                                     | 64             | Special                   |
| 8 by 8 inches .....      | 64                                     | 80             | Extra special             |
| 8 by 10 inches .....     | 80                                     | 96             | Extra-extra special       |

Note. - In domestic preparation, only approximately 20 percent of domestic "punch" may be trimmed to Indian No. 6 grade, but approximately 75 percent of the larger domestic sizes may be recovered as the corresponding Indian grades. Size 6 is divided into small, regular, and large. Small punch is equivalent to the No. 6 small.

Grading according to Indian standards limiting dimensions

| Grade    | Width, inches |         | Length, inches |         |
|----------|---------------|---------|----------------|---------|
|          | Minimum       | Maximum | Minimum        | Maximum |
| 6.....   | 0.5           | 1       | 1              | 2       |
| 5-1/2... | .75           | 1.5     | 1.5            | 3       |
| 5.....   | 1             | 1.7     | 1.7            | 3       |
| 4.....   | 1.5           | 2.5     | 2.5            | 4       |
| 3.....   | 2             | 3.2     | 3.2            | 5       |
| 2.....   | 2             | 3.7     | 3.7            | 7       |
| 1.....   | 3             | 4.9     | 4.9            | 8       |
| A-1..... | 4             | 6.0     | 6.0            | 9       |

Classifying. - Exact classification of mica for quality is extremely difficult, because it depends somewhat on individual interpretations of standards. Domestic mica is classified upon the basis of the quality of the largest usable rectangle of sound area that can be cut from the block, although the edges may be heavily stained or otherwise defective, whereas by the Indian method the average quality of the entire piece is the basis of classification. If the domestic industry is to retain any of the gains made during the second World War period, it will be necessary to prepare sheet mica to full Indian standards. Figure 4 is a chart for Indian grading of mica.

The American Society for Testing Materials has adopted the following standards of quality:

- Clear..... Free of all mineral and vegetable inclusions, stains, air inclusions, waves, or buckles.  
Hard, transparent sheets.
- Clear and slightly stained..... Free of all mineral and vegetable inclusions, cracks, waves, and buckles but may contain slight stains and air inclusions.
- Fair-stained..... Free of mineral and vegetable inclusions and cracks, hard, contains slight air inclusions and is slightly wavy.
- Good-stained..... Free of mineral inclusions and cracks but contains air inclusions, some vegetable inclusions, and may be somewhat wavy.
- Stained..... Free of mineral inclusions and cracks but may contain considerable clay and vegetable stains and may be more wavy and softer than the better qualities.
- Black-stained or spotted..... Same as stained, but contains mineral inclusions.

Black-stained is sometimes separated into four qualities or classes. They are, in descending order of quality, showing increase in degree and distribution of staining: (1) Heavy-stained, (2) light-dotted, (3) black-spotted, and

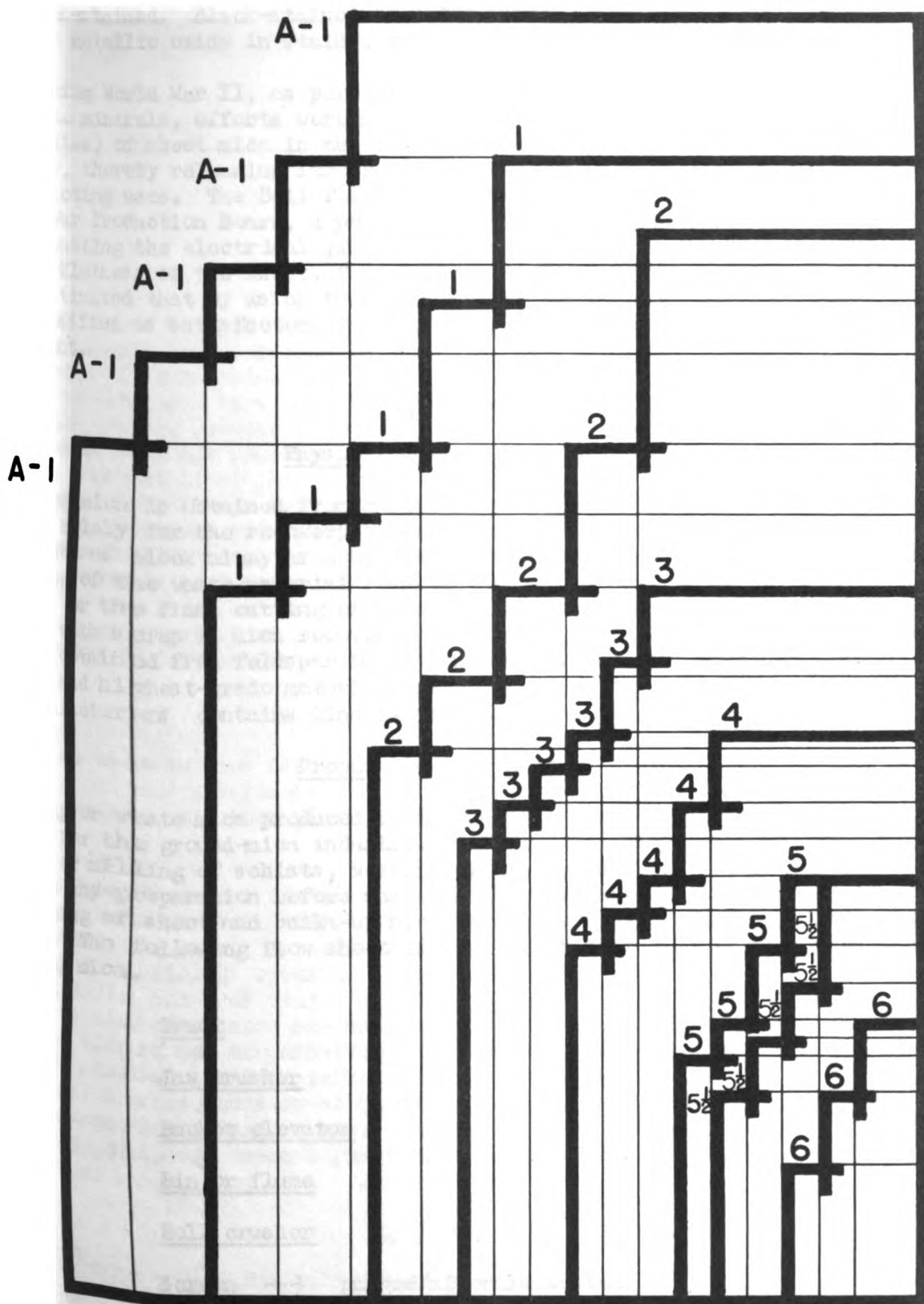


Figure 4. - Chart for grading mica to Indian standard sizes.

(4) black-stained. Black-stained contains varying proportions of iron or other metallic oxide in stains, streaks, or spots.

During World War II, as part of the program of conserving supplies of strategic minerals, efforts were made to increase the use of the lower classes (qualities) of sheet mica in the less exacting uses of the electrical industry, thereby releasing larger quantities of the highest classes for the more exacting uses. The Bell Telephone Laboratories developed, at the request of the War Production Board, a practical scientific instrument for testing and evaluating the electrical qualities of mica, although it cannot be used to test flatness of the sheet, flexibility, or other physical characteristics. It is estimated that by using this machine the quantity of domestic sheet mica now classified as satisfactory for electrical uses could be increased about 20 percent.

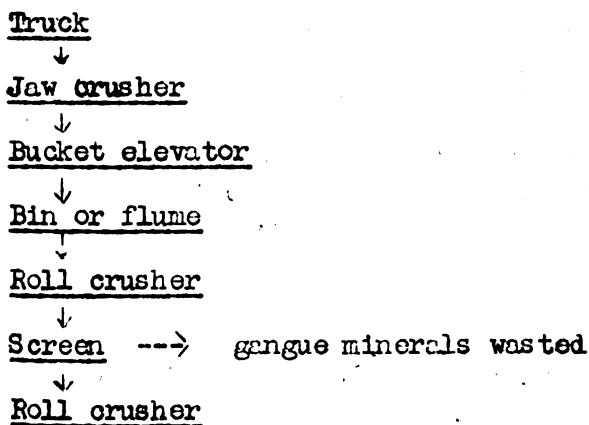
## SCRAP MICA

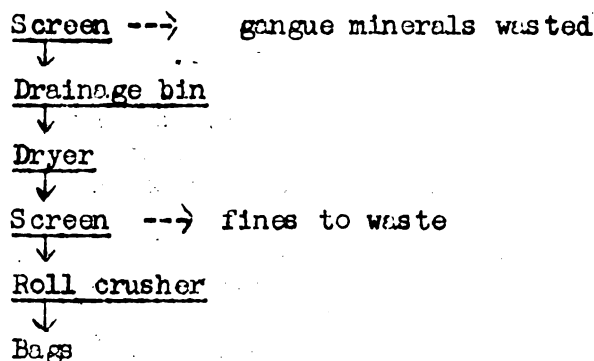
### Physical Characteristics

Scrap mica is obtained from a number of sources. It may come from mines operated solely for the recovery of scrap; as mine scrap resulting from the preparation of block mica; as a byproduct of feldspar mining; as factory scrap consisting of the waste material resulting from the trimming of block mica to sheet, or the final cutting of sheet and built-up mica into usable shapes. Included with scrap is mica recovered by grinding mica schists, washing clay, and that obtained from feldspar flotation plants. Factory scrap is usually the cleanest and highest-grade material, although some scrap obtained from built-up mica manufacturers contains binders that may be detrimental in certain uses.

### Preparation for Market

Scrap or waste mica produced in the United States is utilized as raw material for the ground-mica industry. Only the material recovered from the crushing or milling of schists, washing of clay, and flotation of feldspar undergoes any preparation before sale. Factory scrap and that recovered from the trimming of sheet and built-up mica is simply bagged and sold to the mica grinders. The following flow sheet is typical of that used by companies that mine scrap mica.





The schist is dumped into the jaw crusher, broken up, and washed through the crusher to bucket elevators, which carry the material to a flume. The flume may have one or two outlets, depending on the number of mills operated. From the flume, the material goes through a series of roll crushers and screens, which separate the mica from the gangue of quartz, feldspar, garnet, and clay. The gangue materials are wasted. From the second screen, the mica is carried by bucket elevator to the draining bin. From this bin, it is fed by a screw feeder to a rotary oil-fired dryer, and then by bucket elevator to a 14-mesh screen. The fines from this screen also are wasted. The oversize goes through a roll crusher and is bagged for shipment to mica grinders. Light-colored or white scrap mica commands the highest price. Some companies, therefore, blend the mica before shipping in order to market a product that is light in color. Additional information on the recovery of scrap mica is included in a report by G. Munson and F. F. Clark, of the U. S. Bureau of Mines (16).

#### GROUND MICA

Ground mica has an unctuous feel, and most of its current uses depend upon its appearance and its lubricating, covering, and adhesive properties. It is graded according to manner of grinding (wet or dry), mesh size, color, and freedom from impurities.

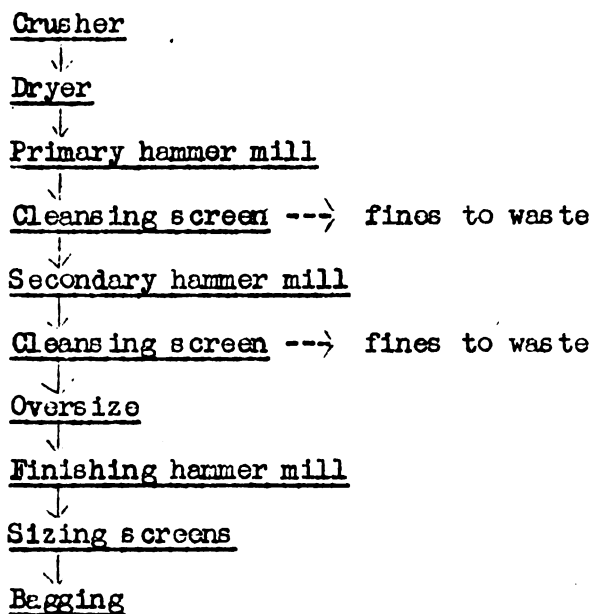
Despite its softness and platy structure, mica is comparatively difficult to grind. Sheet mica is readily amenable to splitting into thinner sheets, but it resists grinding because even the thinnest films or flakes are tough, elastic, and so smooth that they slip over one another. Grinding of mica, therefore, is a shredding and tearing operation rather than the usual crushing action. An additional problem is that the sheen and other valuable characteristics are impaired if the temperature during grinding is too high. Wet-ground mica brings a higher price than dry-ground material, chiefly because it retains its sheen and the edges of the flakes are sharp in contrast to the torn and hackly edges and abraded surfaces of the dry-ground material. Abrasion of flakes gives the product the appearance of flour, reduces the slip, and impairs the ability of the product to mix with liquids.

#### Dry Grinding

Dry-grinding plants include those grinding mica schist, or mica and chlorite schist, and those using scrap mica as head feed. At least two plants beneficiate mined schist by a wet process, dry the product, and use it as feed

for dry-grinding plants. The schist is crushed, dumped into a sluice, and carried to the mill. Roll or rod mills are used to break up the material, separate the mica from the gangue, and remove impurities from between the sheets of the mica books. This product is dried and delivered to the dry-grinding mill.

The process and machinery used in dry grinding vary considerably in accordance with the personal preference of the mill operator. There follows a simplified flow sheet of a mill suitable for dry-grinding schist or the beneficiated product from a schist deposit.



High-speed hammer mills, rod mills, and pulverizers of the cage-disintegrator type equipped with screens or air separators have been used successfully. The discharge from the mill screens is generally fed to multiple-deck vibrating screens, which produce the sizes required. Mesh sizes range from through 6 on 10, or 16 to 250 mesh. Some of the simpler plants, however, make separations only at 40, 60, and 100 mesh.

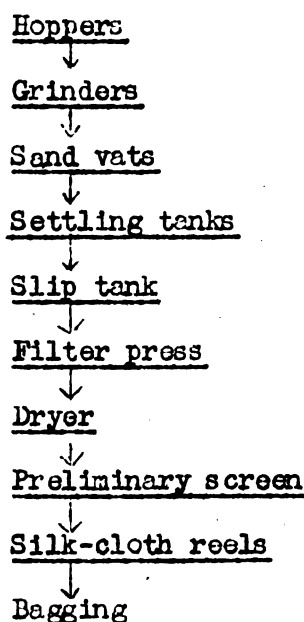
Recovery of mica at the beneficiation plants usually ranges from 12 to 18 percent of the head feed. This product then becomes the head feed for the grinding mill, and recovery at the latter mill averages 90 to 96 percent. Where schist is fed directly to the grinding mill, only about 10 percent of the head feed is recovered. Because some consumers specify color requirements for the finished product, some blending of the head feed is practiced.

Other types of mills in past or present use for dry-grinding are buhr mills, emery mills, and various types of attrition mills. A cylindrical mill or grinding trommel charged with steel slugs was common at one time (24). One Canadian mill ground mica by a shredding action. The mica was fed between two horizontal steel disks carrying rows of studs or teeth. The upper plate rotated and the lower plate remained stationary (19).

## Wet Grinding

Mica is wet-ground in mills that resemble the well-known Chilean mill, which is still utilized for feldspar and sand grinding and formerly was used extensively in ore-dressing plants. The mica-grinding mills may be entirely of wood construction or may be cylindrical steel tanks with bottoms of end-grain wood blocks or with steel-lined concrete side walls and concrete bottoms protected by wood blocks. The bottoms of these mills are flat and do not have a screen or annular launder for continuous discharge. Grinding must be done on wood to preserve the luster or sheen of the mica. Wooden rollers 30 to 40 inches in diameter and with a 20- to 26-inch face rotate and float on the charge. Most of the mills are driven from above, but some of the earlier mills were driven by gears underneath, the drive shaft passing upward through a stuffing box. Obviously, however, such an arrangement afforded excessive leakage or necessitated large quantities of packing materials. The wood blocks in the bottom of the mills are placed end grain up, and the rollers also are assembled with the end grain exposed. Ash, maple, black gum, and pine are used. The inside diameter of the mill ranges from 3 feet in the earlier mills to 10 to 12 feet in present mills, and the rollers revolve at about 20 r.p.m. Grinding can be accelerated by increasing the speed or weighting the rollers. However, this increases friction between wheels and charge, thus increasing the temperature of the mass. Care must be taken, because excessive heat will mar the sheen of the product.

Following is a simplified flow sheet of a typical wet-grinding mica mill.



Scrap muscovite mica is fed through hoppers to the grinding mill, and enough water to keep the rollers on top of the mica is added. When using a batch process with a charge of about 2 short tons of mica, grinding time is 8 hours. Additional water is added during the grinding to keep the temperature of the charge below the boiling point and to maintain the charge as a thick paste. After grinding, the material is discharged from the mill to sand vats.

The mica is water-agitated, and the sand is released and falls to the bottom. From the sand vats, the mica flows to settling tanks. After about 8 hours, the mica has settled to a paste, and the water is siphoned off. This mica paste is shoveled to a slip tank, where it is fluffed by steam and pumped to a filter press, where it is pressed into cakes about 2 feet in diameter and 2 inches thick. The filter press reduces drying time by 50 percent. The dried cakes are then dumped into pot-type dryers, which have revolving paddles to break up the cakes and prevent packing of the mica. Drying time is about 3 hours. From the dryers the mica is elevated to a wire scalping screen to remove wood and other foreign material in preparation for final screening through silk-cloth reels. There may be as many as six reels, and the product varies from 160 to 325 mesh. The finished product is bagged by a screw packer.

Biotite mica may be water-ground by the same process, with the exception that filter-press cakes are table-dried. If pot-type dryers are used, biotite packs into balls ranging in size from a pea to a baseball, and the drying is not uniform.

### Micronized mica

This type of grinding consists of subjecting a charge of scrap mica in a circular chamber to steam pressure from a series of jets which keeps the mica circulating at high speed. There are no moving parts in this machine. Mica is fed into the circular grinding chamber through two 1-inch pipes on opposite sides of the chamber. Steam at 100 pounds pressure superheated to 550° F., issuing from numerous jets around the periphery, keeps the mica circulating at high speed over teeth set at various angles around the inner walls. When the mica reaches the desired size, it gravitates toward the center of the chamber and drops to the primary collector, from which it is bagged. There is a secondary collector that recovers mica from the waste steam pipe. The latter material is not completely dry and is put through the pot dryers at the wet-grinding mill before bagging. Two theoretical mesh sizes of 1,000 and 3,000 mesh are prepared. The mesh size is regulated by the quantity of feed and the steam pressure. A smaller charge and an increase in steam pressure produces the so-called 3,000-mesh material.

## DOMESTIC PRODUCTION

### Sheet Punch and Scrap

According to Sterrett (22), from 1803 to 1867 New Hampshire produced all the mica mined in the United States. No records of the quantity and value mined were kept until 1880, however, when mines had been opened in several other States. Until about 1890, the bulk of the mica used by industry was utilized by the glazing trade, and only large, clear sheet was satisfactory. After 1890, the great growth in the manufacture of electrical apparatus and machinery called for increasing quantities of mica. About the same time, ground mica for use as wallpaper decoration came into demand and provided a market for much of what had been considered waste mica. For the period 1803 to 1885, domestic mica mines furnished virtually all of the large sheet required by industry. After 1885, increasing imports from India began to make inroads on domestic production.

The quantity of imported sheet mica has increased steadily and for many years has accounted for 70 to 85 percent of the total quantity consumed in the United States.

The annual production and value of sheet, punch, scrap, and reclaimed mica from 1920 through 1947 is shown in table 1. Punch and circle mica comprise 85 percent of the total sheet produced in the 1920 to 1947 period. Thus, only 15 percent of the sheet-mica output of the United States is the larger sizes, the best grades of which bring \$1 to \$10 per pound. Much of the larger sheet mica is stained and has air bubbles, cracks, or inclusions of other minerals, which make it unsuitable for critical uses.

Although scrap mica is of low unit value, it comprises, as shown in table 3 and figure 5, 87 to 97 percent of the mica produced in the United States. Scrap and schist mica are valuable only as raw material for use in the manufacture of ground mica. Separate statistics on the recovery of scrap mica were first compiled in 1893 and have been available continuously since that time. Mica recovered from schist was first reported in 1916 from the washing of kaolin and china clay in 1925, and from flotation recovery of feldspar in 1946. Although mica recovered from schists, clay washing, and feldspar flotation plants may be marketed as ground mica, it is reported as a raw material because it represents an original recovery of mica. Table 1 shows that the production of scrap mica did not exceed 10,000 short tons until 1935, and reclaimed-mica production did not reach that tonnage until 1937. The total annual output of scrap and reclaimed mica exceeded 20,000 tons for the first time in 1936 and reached an all-time high of 53,602 tons in 1946.

The steady increase in output of scrap mica is due in part to an ever increasing number of uses for this material. Its continued increase during the recent war, when many nonstrategic commodities were curtailed is attributed to the many essential uses for ground mica in the wartime economic program.

North Carolina, New Hampshire, and Connecticut have for many years been the largest mica-producing States, and North Carolina is the largest producer of scrap and reclaimed mica. The output of sheet and punch mica by these States in the 1920 to 1945 period was, respectively, 19,813,205 pounds, 12,671,160 pounds, and 3,014,839 pounds (see tables 4, 5, and 6) for a total of 35,499,204 pounds, which is 91 percent of the 38,965,752 pounds produced in the United States for that period. This breakdown cannot be given for the years after 1945 except for North Carolina, because separate figures for production in New Hampshire and Connecticut are not available. The production of scrap and reclaimed mica in North Carolina for the 1920 to 1945 period reached 292,422 short tons, or 59 percent of the 601,857 tons produced in the United States for that period.

#### Ground Mica

Ground mica was first marketed in the United States about 1890, when wet-ground mica was first used as a decoration on wallpaper. The use of dry-ground mica in roofing was first reported about 1908. Production figures, however, are not available for ground mica before 1923. Although the first commercial production of ground mica in the United States was the wet-ground

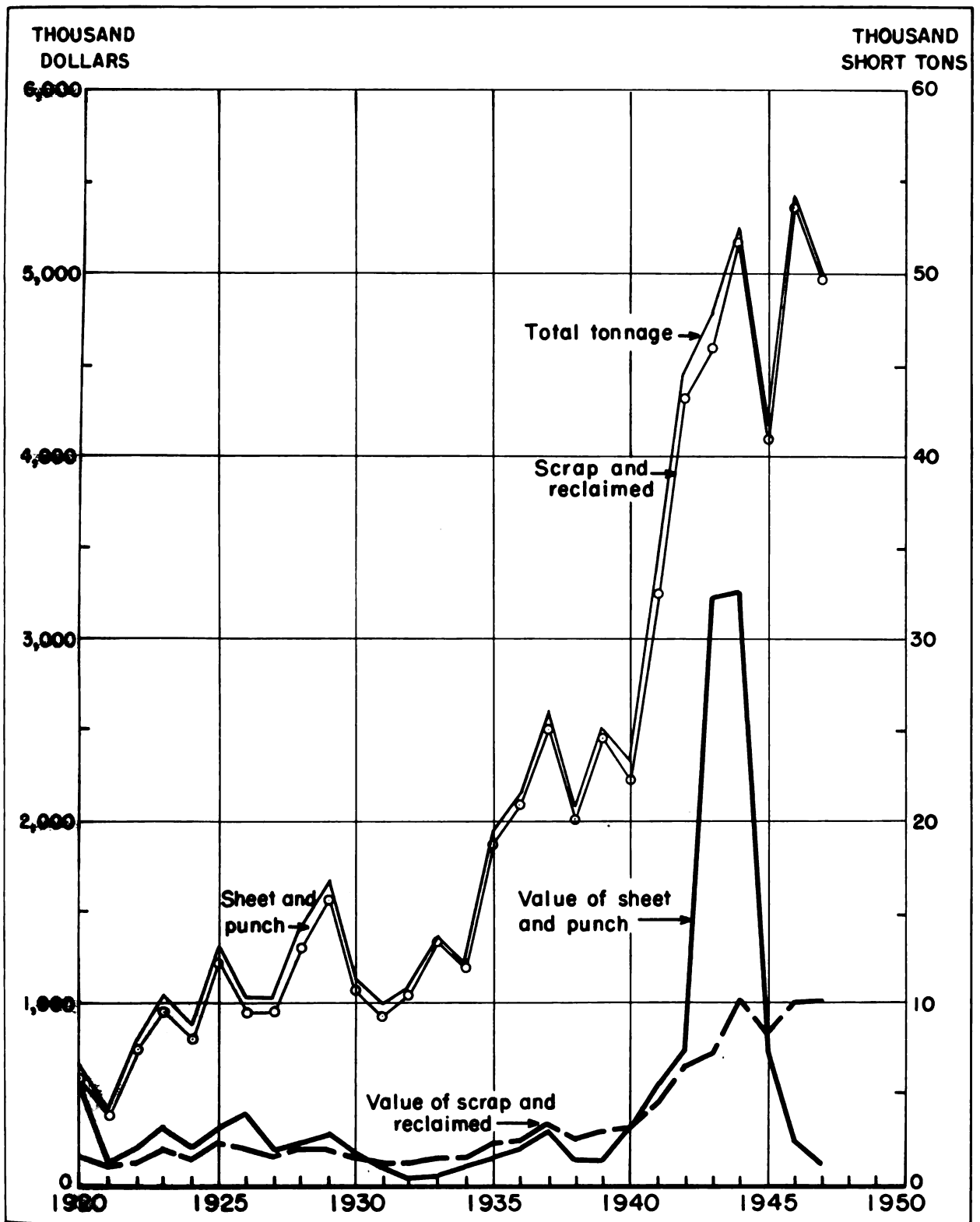


Figure 5. - Production and value of sheet, punch, scrap, and reclaimed mica, 1920-1947.

material, this type has never accounted for more than 35 percent of the total annual output, and for the 1923 to 1947 period (see table 7) accounted for 27 percent of the total output. Annual production of wet-ground mica approximated 3,000 short tons from 1923 to 1936, and then advanced sharply to 7,702 tons in 1939, declined to 6,175 tons in 1940, and reached an all-time peak of 11,505 tons in 1941. The high output is attributed largely to the military demands for wet-ground mica in paints for waterproofing tents and tarpaulins; and as a constituent in plastics, rubber, and welding-rod coatings. Dry-ground mica in the 1923 to 1947 period accounted for 73 percent of the total output and reached a peak of 89 percent in 1944. The 1944 output was also an all-time high. This large production is also attributed to military demands, such as a filler in asphalt landing mats for temporary airfields. Clean, white, low-iron muscovite was in demand for use in glass-bonded insulation for radio sets, and cable and telephone insulation. The output of dry-ground mica declined in 1945 because of a reduction in military requirements and relatively low peacetime demands. The output increased in 1946 and reached a new all-time peak of 55,731 tons in 1947. The increase is attributed to the large postwar construction program with its heavy demands for roofing and paint.

## ECONOMICS

### Economic Considerations in Prospecting, Mining, and Marketing

Many mica mines are small operations, and mining is frequently started with a meager capital outlay. Exploration and development are either slight or lacking entirely, and as a result the opportunity for efficient operation on a long-term basis or expansion at minimum cost are sacrificed. Only the immediately promising outcrops are investigated, and waste material may be thrown over workable ground. This not only results in handling waste several times but limits the number of working faces that may be opened at a given time.

The United States has for many years been the world's largest producer and consumer of mica. Domestic production accounts for about 3 to 12 percent of its requirements of large sheet mica, about 90 percent of punch, circle, and scrap requirements, and less than 1 percent of the splittings required for the built-up mica industry. The bulk of the mica mined in the United States, as in all other countries, is scrap. However, in most other countries the scrap is wasted, and only the sheet and punch material is reported as production. The United States supplies only a small percentage of its large sheet requirements because of the relatively high domestic production and preparation costs. Relatively few men are employed in mica mining, and domestic sheet is generally poorly prepared. During the recent war, when mica mining in the United States reached an all-time peak, about 5,000 were employed in mining, in contrast with a total of about 100,000 in India during the same period.

### Evaluation of Prospects

All block- or sheet-mica deposits of commercial grade have been found in or associated with pegmatites. However, it has not been possible to formulate criteria that will determine exactly the difference between a barren and a productive pegmatite, because a pegmatite that is barren for much of its length

may contain mica in commercial quantities in the remaining part. Thus, not only the right pegmatite but the right part of the pegmatite must be found.

A productive pegmatite, however, is generally one that has a pronounced zonal structure. The presence of zones rich in plagioclase feldspar along the walls of pegmatites is a good indicator of the possible presence of a wall-zoned mica deposit. Exploration of wall-zone deposits, however, should be thorough, because many such deposits are made up of rich shoots of mica separated by leaner portions. Obviously, the size and extent of the entire zone should be considered before operations are started. Cores and bulges in pegmatites should be examined for core-margin deposits. In general, quartz-rich cores are more productive of mica than feldspar cores, but exceptions have occurred. As much of the core as possible should be examined prior to operation.

The size and attitude of both the pegmatite and the enclosed mica deposit must be determined, because these features determine the nature, scale, and cost of mining. Large, tabular, steeply dipping, disseminated deposits favor low-cost open-cut mining, whereas the same type deposit of moderate dip can be operated most efficiently by starting underground operations at an early stage. It is most important, also, that underground operations be planned with reference to the structure of the pegmatite and the wall rocks.

The widespread belief or hope that the quantity and quality of mica will increase with depth or that a pegmatite completely barren at the surface will contain a workable deposit at depth is justifiable only under certain conditions. If detailed study shows that in depth the pegmatite becomes zoned, then it is possible that the quantity of mica may increase or that mica may be found below the surface. Mica books on the outcrop may be soft, water-soaked, split by frost along cleavages, and stained by rust from pyrite or by organic material. These alterations may extend only to shallow depths, but if the pegmatite is badly fractured or the wall rock is rich in pyrite, the staining and fracturing of the books may extend to depths of 50 to 70 feet. Other defects of a more serious nature cause the formation of ruled, reeved, wedge, or A mica. Such defects have no relation to the surface conditions; they are due, rather, to unfavorable circumstances during the formation of the pegmatite or to later deep-seated earth movements long before the pegmatite was exposed to atmospheric conditions. Production records have shown that the number of mines in which the quantity and quality increased in depth are about equally matched by a similar number in which the mines became leaner or the sheets were so distorted at depth that they were satisfactory for marketing only as scrap mica.

### Mining

Mica mining, particularly if conducted by inexperienced operators, involves great financial risk owing to the irregularity of the borders of the pegmatites and the erratic distribution of mica. These features dictate the size and shape of the opening and have an important bearing upon the mining method to be employed. There is a tendency on the part of many miners to work the mines only for present values, with little regard for the future.

The miner testing the deposit feels he must have immediate return for his labor, and accordingly he follows the mica wherever found by pits, crosscuts, inclines, shafts, and irregularly spaced tunnels. Thus, the mine has been given a poor start, and subsequent systematic mining of such a property is difficult. There are some cases, however, because of the scattered occurrence of the mica, in which systematic mining is almost impossible.

Some mica mines produce only scrap suitable for grinding, and others produce scrap and variable percentages of sheet and punch. The ratio of production of sheet to punch is important to any prospective producer, as is the relationship of sizes and qualities, because profitable operation may depend upon marketing considerable quantities of low-value punch. The yield of usable sheet mica varies considerably in different deposits but is always small. Generally, 2 to a maximum of 6 percent of the total rock mined is marketable as raw block or sheet mica. A large part of this is saleable only as punch and circle mica, and a minor amount as rectangular block mica. Cobbing, rifting, and trimming eliminate 50 to 70 percent of this block mica, and most of the trimmed product may be the smallest size, 1 by 1-inch. Rarely more than 15 percent will be 3 by 4 inches and larger, and there is always the possibility of a large percentage of the sheets being heavy-stained or otherwise unsuitable for critical needs.

Ordinarily, mica miners have three choices in disposing of their mica; first, and most commonly, they sell their entire "mine-run" output to a trimmer or broker; second, they may sell the roughly graded sheet to the trimmer or broker; and third, they may prepare the mica for the consumer market. It must be recognized that the quality of mica will vary from mine to mine and from time to time in the same mine. It is impossible, therefore, to be certain of the value of the output of any mine over a period of time. In view of the large losses in quantity and the difficulties and costs of proper preparation, most small miners dispose of the entire "mine run" to a trimmer or broker. The owner sometimes leases his property for mica mining and is paid a royalty on the mica as removed from the ground.

### Marketing

The production of sheet mica, including punch, in the United States, as shown in table 3, has never accounted for more than 13 percent of the total output and in the 1920 to 1947 period was only 3 percent. Scrap and reclaimed mica, therefore, make up 87 to 97 percent of the total domestic mica marketed in the United States. The annual production and value of sheet, punch, scrap, and reclaimed mica for the 1920 to 1947 period is shown graphically in figure 5. From this graph it can be seen that the value of scrap and reclaimed mica produced in the United States from 1931 through 1947, with the exception of part of the recent war period, 1941 to 1944, is greater than the value of the sheet and punch marketed. The high values for sheet and punch mica during the war are attributed to the subsidized prices of \$6 to \$8 per pound for the small sizes of the strategic grades of sheet and 40 cents per pound for punch during the period, in contrast to the normal peacetime values of 10 to 50 cents per pound for sheet and 3 or 4 cents to 20 cents for punch. These abnormal values, therefore, should not be considered in an economic study of the normal or peacetime trend of the mica industry. The low unit value of sheet mica in the

United States is attributed to the large percentage of punch produced and the poor preparation of the larger sheet. Except for the recent war period, when the strategic grades of domestic mica were prepared three-quarters or full trim, sheet mica in the United States has been marketed as half trim material. For the 1920 to 1947 period (see table 1), 85 percent of the total sheet produced was punch mica with an average value of 9 cents per pound. Larger sheet, because of the subsidized prices during the war, brought an average of \$1.32 per pound.

Half-trimmed domestic sheet mica must be further processed to full trim before it is usable by the manufacturer, in contrast to Indian and Brazilian sheet, which is offered for sale as full-trim material at a price comparable to the domestic product. The domestic mica miner or trimming-shed operator contends that the cost of preparing domestic mica to full trim is greater than the market price obtainable for the finished material. This opinion is confirmed by a cost study made during the recent war, which showed that the cost of mining sheet mica in the United States was about \$3 per pound. Preparation of the mined mica to full-trim condition involves an additional \$2 to \$3 per pound, or a total cost of about \$6 per pound. During World War II, the average price paid by the Metals Reserve Co. for imported strategic grades of sheet mica averaged about \$1.50 per pound. Thus, a domestic miner or trimmer could not compete economically with Indian mica miners or processors whose pay scale was about 16 to 32 cents per day, and total mining and trimming costs were about 50 to 80 cents per pound. Although costs have increased in India, the Indian producer still has a competitive advantage. It is believed, therefore, that a successful sheet-mica operation in the United States, with few exceptions, must be one in which the major product is a large volume of a relatively low-priced but stable commodity, such as scrap mica or feldspar, and where the sheet mica is recovered as a byproduct. The term "strategic mica" was much used for the better grades of sheet mica during World War II. Perhaps a better term would be "mica of military grade," which would include all full-trimmed muscovite sheet mica of sizes 1 by 1 inch and larger of the qualities known as clear and slightly stained, fair-stained, and good-stained.

Table 2 shows the quantity of domestic mica produced in the 1920 to 1947 period that is believed to be of military grade. A summary of the estimated military-grade mica produced in the 1880 to 1919 period also is included in table 2. During the war, the quantity of domestic mica that met military standards was about 15 percent of the total annual output, but actual figures are not available on the quantity of sheet mica of military grade produced before and after the war, as most sheet mica in the United States is prepared only as half-trim material. It is believed, however, that 10 to 15 percent of the sheet and punch mica produced in the United States would meet the standards of military-grade mica. The quantity shown as military-grade represents (except for 1942 to 1945, for which actual figures are available) approximately 12 percent of the annual domestic output of sheet and punch mica.

#### MICA USES

The perfect cleavage, flexibility, chemical and physical stability, transparency, high dielectric strength, and luster of mica make it serviceable in many industries. From the defense viewpoint, the most important of these at present is the electrical industry.

Ancient and extensive workings in the southern Appalachians and mica found in the graves of mound builders in the Mississippi Valley offer conclusive proof that mica was mined in the United States before the arrival of the white man. Except for ornaments, the uses for which this mica was mined are unknown, however. The first modern use known for sheet mica in the United States was as windows in stoves. Mica for such use came from the Ruggles mine in New Hampshire, which was opened in 1803. About 1890, a use for the large quantities of scrap or waste mica, from sheet-mica operations, was developed. Wet-ground mica made from scrap was utilized as a decoration on wallpaper. Additional uses for sheet mica were as chimneys for lamps, shades for open-flame lamps, and nonbreakable spectacles for industrial use. The use of mica expanded greatly with the invention of built-up mica in 1894. This product, made of mica films or splittings cemented by shellac or resin, can be made into sheets of almost any desired size. The sheets can be milled to uniform thickness or can be made into tubes of many and varied shapes. As the electrical industry increased the insulation and dielectric qualities of mica became more important. It may be said that possibly because of these two properties of mica the electrical industry prospered. As the size of electric motors, transformers, and generators increased, it became very difficult to obtain sheet mica in large sizes or in large enough quantities for the many parts of these electrical products. Thus handicapped by the sizes of sheet mica available, motors were held to small sizes, or the larger motors were forced to use other insulating products, which reduced operating temperatures so greatly that only a small part of its potential current was delivered. The invention of built-up mica and the manufacture of large sheets solved this problem. Some of the electrical uses for mica are for insulating rings, sleeves, bushings, and commutation-segment insulation in electric motors; also in generators, condensers, electric-light bulbs, sparkplugs, fuses, and heating elements of flat irons. By 1913, additional uses for ground mica had been found, such as filler in rubber, as a decorative facing on concrete, and in the tempering and annealing of steel. Sheet mica also was used as lantern slides in the photographic industry. A listing of the uses of sheet and ground mica, classified essential, less essential, and nonessential, was reported by W. T. Schaller in 1918 (18). Essential uses included electrical insulation, which utilizes film, sheet, splittings, and built-up mica board. Less-essential uses included sheet mica used in stove fronts, lamp chimneys, and shades, splittings and built-up mica used in electric heating devices, and ground mica used as pipe and boiler covering, roofing material, an annealing agent for steel, and as a lubricant for wood bearings. The nonessential uses included utilization of sheet mica in phonograph diaphragms and ground mica as a decoration, a lubricant for metal bearings, filler in rubber, and various other manufactured products. It is interesting to note in this classification that scrap mica, the raw material for ground mica, is not reported, but splittings used in the manufacture of built-up mica board is reported. By 1938, 90 percent of the sheet and built-up mica consumed in the United States was utilized by the electrical industry. The essential uses for mica, as reported in "The Mica Industry," report 130 of the United States Tariff Commission, in 1938 were sheet mica for use in radio condensers and airplane sparkplugs, and built-up mica as commutator segments and V-rings for motors and generators, and in armatures and transformers. There was little change in the less-essential uses between 1918 and 1938 other than a larger annual consumption of mica in some of these categories, particularly wet-ground mica

in the manufacture of paint. The greatest change in the nonessential uses during this period is the addition to this classification, by 1938, of the sheet and built-up mica utilized in receivers, transformers, and condensers by the telephone industry and in neon lights. Paper or bakelite capacitors have replaced mica in the telephone industry.

The essential uses in 1947 were similar to those given in 1938, with the exception that sheet mica for airplane sparkplugs has been deleted from this class, and the quality requirements of the mica utilized in some of the remaining essential uses has been reduced. Little change has taken place in the less-essential uses other than a reduction in the quantities required for stove fronts and lamp chimneys and shades. The number of uses for ground mica, however, have increased greatly. Large quantities of roofing-grade, dry-ground mica were consumed in the manufacture of rolled asphalt mats used in the construction of airfield landing strips in the European theater of operations, and in the manufacture of pipeline enamel used in the insulation of the large gas and oil pipelines constructed from central and southwestern United States to the eastern seaboard. Clear, white, low-iron muscovite ground mica is utilized in the manufacture of glass-bonded insulation for use in the manufacture of radio sets. The use of wet-ground mica by the paint industry also has increased greatly. It has been reported that if 200,000 to 300,000 shorts tons of wet-ground mica were available annually to paint manufacturers, the durability of paint for the outside of houses and industrial buildings would be increased greatly.

Mica is no longer suitable for sparkplugs in high-speed internal-combustion engines, because the temperatures of 1,000° F. and above attained by these motors cause the mica to decompose. It loses its chemically combined water of crystallization, which destroys its normal insulating and dielectric qualities. Much of the gasoline now used as fuel contains tetraethyl lead, which upon combustion forms lead compounds that react with mica to form a low-melting-point lead-silicate glass. This glass is a good conductor of electricity when hot, which causes misfiring of sparkplugs in engines operating at high temperatures. Mica plugs are now used primarily in industrial engines and in small, air-cooled, private airplanes, which use fuel containing little or no lead.

#### SALIENT STATISTICS OF THE MICA INDUSTRY

The following tables comprise the more important statistical data relating to the mica industry. Most of them show figures up to 1947 only. Production in 1948 and 1949 was much smaller than during the war years, and the data are less complete. Accordingly, figures for these years have been omitted from some of the tables, but they may be found in part in the chapters on mica in the Minerals Yearbooks for 1948 and 1949.

TABLE 1. - Domestic-sheet, punch, and scrap mica sold or used in the United States, 1920-1947

| Year  | Sheet     |            | Punch      |            | Total sheet and punch |            | Scrap      |           | Reclaimed  |           | Total scrap and reclaimed |            | Total sheet, punch, scrap, and reclaimed |            | Average price Sheet, Scrap, per short ton |       |
|-------|-----------|------------|------------|------------|-----------------------|------------|------------|-----------|------------|-----------|---------------------------|------------|------------------------------------------|------------|-------------------------------------------|-------|
|       | Pounds    | Value      | Pounds     | Value      | Pounds                | Value      | Short tons | Value     | Short tons | Value     | Short tons                | Value      | Short tons                               | Value      | Short tons                                | Value |
| 1920  | 529,940   | \$431,202  | 1,153,540  | \$115,770  | 1,683,480             | \$546,972  | 5,723      | \$167,017 | -          | 5,723     | \$167,017                 | 6,565      | \$713,989                                | \$0.32     | \$29.18                                   |       |
| 1921  | 66,058    | 50,997     | 675,787    | 67,516     | 741,845               | 118,513    | 2,577      | 56,849    | 1,000      | \$37,262  | 3,777                     | 94,111     | 4,148                                    | 212,624    | 0.16                                      | 24.91 |
| 1922  | 166,535   | 123,174    | 911,433    | 71,127     | 1,077,968             | 194,301    | 6,641      | 114,045   | 913        | 23,157    | 7,554                     | 137,202    | 8,093                                    | 331,503    | 0.17                                      | 18.16 |
| 1923  | 269,430   | 176,225    | 1,793,749  | 134,955    | 2,063,179             | 311,180    | 8,054      | 129,695   | 1,565      | 65,484    | 9,559                     | 195,179    | 10,590                                   | 506,359    | 0.15                                      | 20.41 |
| 1924  | 155,678   | 98,750     | 1,305,219  | 113,285    | 1,460,897             | 212,035    | 4,709      | 87,242    | 3,429      | 37,675    | 8,138                     | 143,396    | 8,868                                    | 355,431    | 0.14                                      | 17.62 |
| 1925  | 1,003,689 | 246,434    | 790,183    | 75,528     | 1,793,872             | 321,962    | 9,695      | 173,537   | 2,665      | 64,544    | 12,360                    | 238,081    | 13,257                                   | 560,043    | 0.17                                      | 19.27 |
| 1926  | 329,189   | 172,131    | 1,842,970  | 228,053    | 2,172,159             | 400,184    | 7,043      | 136,643   | 2,434      | 70,000    | 9,477                     | 206,643    | 10,563                                   | 606,837    | 0.18                                      | 21.80 |
| 1927  | 197,750   | 117,471    | 1,314,742  | 95,011     | 1,512,492             | 212,482    | 6,430      | 119,883   | 3,107      | 48,595    | 9,537                     | 168,478    | 10,293                                   | 380,960    | 0.14                                      | 17.65 |
| 1928  | 213,295   | 140,025    | 1,468,482  | 90,931     | 1,681,777             | 230,956    | 9,557      | 159,788   | 3,521      | 53,079    | 13,078                    | 212,867    | 13,919                                   | 443,823    | 0.14                                      | 16.27 |
| 1929  | 283,084   | 187,332    | 1,752,044  | 98,989     | 2,035,128             | 286,321    | 6,253      | 117,901   | 8,595      | 71,545    | 15,848                    | 189,446    | 16,866                                   | 475,767    | 0.14                                      | 18.00 |
| 1930  | 211,703   | 116,077    | 1,253,782  | 61,230     | 1,465,485             | 177,307    | 6,732      | 109,100   | 4,009      | 59,898    | 10,741                    | 168,998    | 11,474                                   | 346,305    | 0.12                                      | 15.73 |
| 1931  | 205,306   | 78,513     | 757,647    | 33,317     | 962,953               | 111,830    | 6,621      | 99,415    | 2,727      | 22,722    | 9,348                     | 122,137    | 9,829                                    | 233,967    | 0.12                                      | 13.00 |
| 1932  | 80,485    | 37,906     | 258,512    | 7,976      | 338,997               | 45,882     | 7,040      | 83,777    | 3,626      | 38,380    | 10,666                    | 122,157    | 10,835                                   | 168,039    | 0.14                                      | 11.45 |
| 1933  | 111,297   | 42,980     | 253,243    | 10,199     | 364,540               | 53,179     | 8,751      | 98,159    | 4,729      | 61,280    | 13,480                    | 159,439    | 13,662                                   | 212,618    | 0.15                                      | 11.82 |
| 1934  | 158,372   | 74,172     | 425,156    | 16,096     | 583,528               | 90,268     | 7,719      | 99,791    | 4,218      | 66,831    | 11,937                    | 166,622    | 12,229                                   | 256,890    | 0.15                                      | 13.95 |
| 1935  | 266,306   | 132,763    | 670,327    | 28,387     | 936,633               | 161,150    | 12,185     | 132,606   | 6,667      | 111,345   | 18,852                    | 243,951    | 19,320                                   | 405,101    | 0.17                                      | 12.94 |
| 1936  | 300,773   | 155,493    | 1,018,460  | 48,386     | 1,319,233             | 203,879    | 12,697     | 133,251   | 8,258      | 127,343   | 20,955                    | 260,594    | 21,615                                   | 464,473    | 0.15                                      | 12.44 |
| 1937  | 381,638   | 214,751    | 1,312,900  | 70,493     | 1,694,538             | 285,244    | 14,640     | 205,103   | 10,536     | 149,634   | 25,196                    | 354,737    | 26,043                                   | 639,981    | 0.17                                      | 14.08 |
| 1938  | 165,386   | 93,767     | 774,121    | 45,566     | 939,507               | 139,333    | 13,707     | 169,780   | 6,550      | 86,602    | 20,257                    | 256,382    | 20,727                                   | 395,715    | 0.15                                      | 12.66 |
| 1939  | 147,953   | 99,756     | 665,755    | 39,207     | 813,708               | 138,963    | 14,661     | 202,996   | 10,011     | 108,899   | 24,672                    | 311,895    | 25,079                                   | 450,858    | 0.17                                      | 12.64 |
| 1940  | 220,132   | 175,598    | 1,405,305  | 116,087    | 1,625,437             | 291,685    | 12,712     | 176,419   | 9,674      | 138,148   | 22,386                    | 314,565    | 23,199                                   | 606,250    | 0.18                                      | 14.05 |
| 1941  | 324,216   | 359,911    | 2,342,237  | 206,947    | 2,666,453             | 566,858    | 16,917     | 257,303   | 15,583     | 185,486   | 32,500                    | 442,789    | 33,833                                   | 1,009,647  | 0.21                                      | 13.62 |
| 1942  | 336,199   | 442,130    | 2,425,645  | 282,900    | 2,761,844             | 725,030    | 22,782     | 355,314   | 20,481     | 315,807   | 43,262                    | 671,165    | 44,643                                   | 1,396,195  | 0.26                                      | 15.51 |
| 1943  | 757,116   | 2,754,787  | 2,691,083  | 473,955    | 3,448,199             | 3,228,742  | 22,025     | 423,174   | 24,113     | 314,851   | 46,138                    | 738,025    | 47,862                                   | 3,966,767  | 0.94                                      | 16.00 |
| 1944  | 687,911   | 3,115,076  | 835,402    | 147,635    | 1,523,313             | 3,262,711  | 29,620     | 603,505   | 22,107     | 485,567   | 51,727                    | 1,089,072  | 52,489                                   | 4,351,783  | 2.14                                      | 21.05 |
| 1945  | 131,729   | 571,226    | 1,166,858  | 166,116    | 1,298,587             | 737,342    | 26,104     | 487,807   | 15,046     | 324,515   | 41,060                    | 812,322    | 41,709                                   | 1,549,664  | 0.57                                      | 15.50 |
| 1946  | 91,976    | 91,916     | 986,891    | 126,039    | 1,078,867             | 217,955    | 38,405     | 750,883   | 15,967     | 290,540   | 53,602                    | 1,041,423  | 54,741                                   | 1,259,378  | 0.20                                      | 19.43 |
| 1947  | 71,757    | 69,011     | 343,832    | 47,099     | 415,589               | 116,110    | 35,199     | 709,745   | 14,598     | 385,833   | 49,797                    | 1,095,578  | 50,005                                   | 1,211,688  | 0.28                                      | 22.00 |
| Total | 7,864,903 | 10,369,574 | 32,592,305 | 13,018,800 | 40,460,208            | 13,388,374 | 374,659    | 6,360,728 | 226,968    | 3,826,187 | 601,627                   | 10,186,915 | 621,857                                  | 23,512,645 | 0.28                                      | 16.86 |

TABLE 2. - Total sheet and military-grade sheet mica produced in the United States 1880-1947, pounds

| Year           | Total <sup>1/</sup><br>sheet and punched | Military-grade <sup>2/</sup><br>sheet |
|----------------|------------------------------------------|---------------------------------------|
| 1880-1919..... | 23,615,785                               | 2,833,774                             |
| 1920.....      | 1,683,480                                | 202,018                               |
| 1921.....      | 741,845                                  | 89,021                                |
| 1922.....      | 1,077,968                                | 129,356                               |
| 1923.....      | 2,063,179                                | 247,581                               |
| 1924.....      | 1,460,897                                | 175,308                               |
| 1925.....      | 1,793,822                                | 215,264                               |
| 1926.....      | 2,172,159                                | 260,659                               |
| 1927.....      | 1,512,492                                | 181,499                               |
| 1928.....      | 1,681,777                                | 201,813                               |
| 1929.....      | 2,035,128                                | 244,215                               |
| 1930.....      | 1,465,485                                | 175,858                               |
| 1931.....      | 962,953                                  | 115,554                               |
| 1932.....      | 538,997                                  | 40,680                                |
| 1933.....      | 364,540                                  | 45,745                                |
| 1934.....      | 583,529                                  | 70,023                                |
| 1935.....      | 936,633                                  | 112,396                               |
| 1936.....      | 1,319,233                                | 158,310                               |
| 1937.....      | 1,694,538                                | 203,345                               |
| 1938.....      | 939,507                                  | 112,741                               |
| 1939.....      | 813,708                                  | 97,645                                |
| 1940.....      | 1,625,437                                | 195,052                               |
| 1941.....      | 2,666,453                                | 319,974                               |
| 1942.....      | 2,761,844                                | 387,006                               |
| 1943.....      | 3,448,199                                | 731,627                               |
| 1944.....      | 1,523,313                                | 822,394                               |
| 1945.....      | 1,298,587                                | 105,180                               |
| 1946.....      | 1,078,867                                | 129,464                               |
| 1947.....      | 415,589                                  | 49,870                                |
| Total          | 64,075,942                               | 8,651,371                             |

<sup>1/</sup> Figures obtained from Minerals Yearbook of the Bureau of Mines.

<sup>2/</sup> Defined as 12 percent of total sheet and punch as estimated by a Department of Interior Committee in a study of domestic reserves in 1944.

TABLE 3. - Comparison of production and value of sheet, punch, and scrap mica in the United States/

| Year      | Sheet and punch,<br>short tons | Percent<br>of<br>total | Value       | Percent<br>of<br>total | Scrap,<br>short tons | Percent<br>of<br>total | Percent<br>of<br>total |            | Total<br>Value |             |
|-----------|--------------------------------|------------------------|-------------|------------------------|----------------------|------------------------|------------------------|------------|----------------|-------------|
|           |                                |                        |             |                        |                      |                        | Value                  | Short tons |                |             |
| 1880-1919 | 11,808                         | 13                     | \$3,659,504 | 89                     | 72,999               | 87                     | \$1,017,044            | 11         | 84,807         | \$9,676,548 |
| 1920-1947 | 20,230                         | 3                      | 13,388,374  | 56                     | 601,627              | 97                     | 10,186,915             | 44         | 621,857        | 23,575,289  |

1/ Tonnage and value figures obtained from Mineral Resources of the United States and Minerals Yearbook, published, respectively, by the U. S. Geological Survey and the U. S. Bureau of Mines.

TABLE 4. - Sheet, punch, and scrap mica sold or used in North Carolina, 1920-451/

| Year     | Sheet     |           | Punch      |           | Total                      |           | Scrap         |           | Total         |            |
|----------|-----------|-----------|------------|-----------|----------------------------|-----------|---------------|-----------|---------------|------------|
|          | Pounds    | Value     | Pounds     | Value     | sheets and punch<br>Pounds | Value     | Short<br>tons | Value     | Short<br>tons | Value      |
| 1920...  | 361,312   | \$335,499 | 723,634    | \$70,155  | 1,084,946                  | \$405,654 | 2,823         | \$91,653  | 3,365         | \$497,307  |
| 1921...  | 57,171    | 40,625    | 173,361    | 11,226    | 230,532                    | 51,851    | 1,353         | 30,496    | 1,468         | 82,347     |
| 1922...  | 137,906   | 101,474   | 406,589    | 18,293    | 544,495                    | 119,767   | 4,205         | 65,923    | 4,477         | 185,690    |
| 1923...  | 224,894   | 149,903   | 905,389    | 38,414    | 1,130,283                  | 188,317   | 5,005         | 95,128    | 5,570         | 283,445    |
| 1924...  | 137,233   | 84,580    | 460,152    | 24,076    | 597,385                    | 108,656   | 6,641         | 115,774   | 6,940         | 224,430    |
| 1925...  | 128,251   | 75,313    | 464,227    | 30,063    | 592,478                    | 105,376   | 7,095         | 124,818   | 7,391         | 230,194    |
| 1926...  | 160,463   | 116,639   | 539,850    | 33,723    | 700,313                    | 150,362   | 5,314         | 124,048   | 5,664         | 274,410    |
| 1927...  | 136,994   | 87,204    | 528,366    | 27,310    | 665,360                    | 114,514   | 5,409         | 93,670    | 5,741         | 208,184    |
| 1928...  | 137,467   | 96,420    | 639,928    | 33,286    | 777,395                    | 129,706   | 8,739         | 132,119   | 9,127         | 261,825    |
| 1929...  | 157,033   | 110,234   | 737,167    | 40,059    | 894,200                    | 150,293   | 8,346         | 153,722   | 8,793         | 304,815    |
| 1930...  | 138,858   | 81,884    | 610,216    | 30,567    | 749,074                    | 112,451   | 5,904         | 98,400    | 6,279         | 210,851    |
| 1931...  | 79,060    | 38,763    | 310,366    | 12,894    | 389,426                    | 51,657    | 6,872         | 84,818    | 7,066         | 136,475    |
| 1932...  | 41,893    | 15,416    | 85,803     | 2,906     | 127,696                    | 18,322    | 6,237         | 71,842    | 6,301         | 90,164     |
| 1933...  | 44,971    | 17,046    | 117,701    | 4,067     | 162,672                    | 21,107    | 8,968         | 102,830   | 9,049         | 123,937    |
| 1934...  | 67,414    | 29,594    | 225,967    | 9,080     | 293,381                    | 38,674    | 7,255         | 101,985   | 7,402         | 140,659    |
| 1935...  | 111,549   | 59,234    | 410,041    | 18,364    | 512,590                    | 77,598    | 11,831        | 153,553   | 12,087        | 213,151    |
| 1936...  | 154,531   | 90,548    | 575,915    | 29,105    | 730,496                    | 119,653   | 10,840        | 131,138   | 11,205        | 250,791    |
| 1937...  | 248,669   | 171,513   | 795,659    | 46,663    | 1,044,328                  | 218,176   | 12,988        | 209,212   | 13,510        | 427,388    |
| 1938...  | 179,590   | 61,678    | 453,056    | 26,201    | 632,646                    | 87,879    | 11,959        | 161,598   | 12,275        | 249,477    |
| 1939...  | 80,554    | 50,715    | 320,616    | 18,629    | 401,170                    | 69,344    | 13,913        | 184,377   | 14,114        | 253,721    |
| 1940...  | 153,983   | 139,940   | 848,663    | 78,214    | 1,002,646                  | 218,154   | 11,595        | 173,327   | 12,096        | 391,481    |
| 1941...  | 174,514   | 194,428   | 1,440,349  | 124,355   | 1,614,863                  | 318,783   | 18,234        | 268,596   | 19,041        | 587,379    |
| 1942...  | 203,555   | 324,730   | 1,451,340  | 180,904   | 1,654,895                  | 505,634   | 24,145        | 485,560   | 24,972        | 991,194    |
| 1943...  | 358,104   | 1,612,789 | 1,543,016  | 159,535   | 1,901,120                  | 1,772,324 | 25,295        | 516,367   | 26,246        | 2,288,691  |
| 1944...  | 340,195   | 1,461,600 | 474,680    | 69,025    | 814,875                    | 1,530,625 | 29,774        | 750,285   | 30,181        | 2,280,910  |
| 1945...  | 72,562    | 160,766   | 491,428    | 82,292    | 563,990                    | 243,058   | 30,682        | 709,334   | 30,964        | 952,392    |
| Total... | 4,088,726 | 5,708,529 | 15,724,479 | 1,219,406 | 19,813,205                 | 6,927,935 | 592,422       | 5,140,573 | 302,329       | 12,158,508 |

1/ Figures obtained from the Bureau of Mines Minerals, Yearbook.

TABLE 5. - Sheet, punch, and scrap mica sold or used in New Hampshire, 1920-1945<sup>1/</sup>

| Year     | Sheet     |           | Punch      |           | Sheet and Punch |           | Scrap      |          | Total      |           |
|----------|-----------|-----------|------------|-----------|-----------------|-----------|------------|----------|------------|-----------|
|          | Pounds    | Value     | Pounds     | Value     | Pounds          | Value     | Short tons | Value    | Short tons | Value     |
| 1920...  | 116,698   | \$58,493  | 168,164    | \$25,318  | 284,862         | \$83,811  | 435        | \$12,877 | 577        | \$96,688  |
| 1921...  | 5,791     | 8,015     | 485,952    | 55,234    | 491,743         | 63,249    | 537        | 10,613   | 783        | 73,862    |
| 1922...  | 22,095    | 13,070    | 453,552    | 50,170    | 475,647         | 63,240    | 238        | 5,838    | 476        | 69,078    |
| 1923...  | 27,753    | 15,221    | 807,998    | 92,453    | 835,751         | 107,674   | 1,078      | 25,871   | 1,496      | 133,545   |
| 1924...  | 3,540     | 5,638     | 740,593    | 83,099    | 744,133         | 88,737    | 492        | 9,498    | 864        | 98,235    |
| 1925...  | 853,250   | 158,762   | 267,607    | 40,096    | 1,120,857       | 198,858   | 1,953      | 47,525   | 2,513      | 246,383   |
| 1926...  | 151,837   | 47,040    | 1,220,053  | 188,850   | 1,371,890       | 235,890   | 1,738      | 58,213   | 2,424      | 274,103   |
| 1927...  | 46,000    | 18,105    | 674,219    | 60,744    | 720,219         | 78,849    | 1,284      | 22,909   | 1,644      | 101,758   |
| 1928...  | 46,368    | 18,116    | 727,775    | 45,354    | 744,143         | 63,470    | 1,291      | 25,232   | 1,678      | 88,702    |
| 1929...  | 71,226    | 33,772    | 913,552    | 48,885    | 984,778         | 82,657    | 1,657      | 35,977   | 2,149      | 118,634   |
| 1930...  | 56,860    | 24,029    | 616,204    | 29,275    | 673,064         | 53,304    | 449        | 8,743    | 786        | 62,047    |
| 1931...  | 91,996    | 19,026    | 349,168    | 17,342    | 441,164         | 36,368    | 295        | 5,465    | 516        | 41,833    |
| 1932...  | 24,527    | 14,371    | 121,487    | 3,607     | 146,014         | 17,978    | 344        | 5,585    | 417        | 23,563    |
| 1933...  | 50,131    | 18,068    | 117,333    | 3,940     | 167,464         | 22,008    | 532        | 9,563    | 616        | 31,571    |
| 1934...  | 42,922    | 10,635    | 118,508    | 3,788     | 161,430         | 14,423    | 537        | 9,529    | 618        | 23,952    |
| 1935...  | 36,474    | 9,858     | 95,112     | 3,869     | 131,586         | 13,727    | 394        | 5,335    | 460        | 19,062    |
| 1936...  | 46,877    | 12,787    | 238,845    | 10,133    | 285,822         | 22,920    | 250        | 3,610    | 393        | 26,530    |
| 1937...  | 39,626    | 11,602    | 195,429    | 8,517     | 235,055         | 20,119    | 306        | 4,397    | 423        | 24,516    |
| 1938...  | 32,128    | 14,434    | 76,168     | 3,820     | 108,296         | 18,254    | 127        | 1,789    | 181        | 20,043    |
| 1939...  | 2,135     | 1,650     | 41,535     | 2,088     | 43,670          | 3,738     | 105        | 1,592    | 127        | 5,330     |
| 1940...  | 10,634    | 2,797     | 167,969    | 10,747    | 178,603         | 13,544    | 31         | 579      | 120        | 14,123    |
| 1941...  | 26,113    | 28,932    | 368,794    | 36,172    | 394,907         | 65,104    | 171        | 3,700    | 368        | 68,804    |
| 1942...  | 52,651    | 31,675    | 290,288    | 26,320    | 342,939         | 57,995    | 303        | 7,234    | 474        | 65,229    |
| 1943...  | 208,664   | 411,838   | 491,879    | 171,705   | 700,543         | 583,543   | 1,148      | 28,643   | 1,498      | 612,186   |
| 1944...  | 129,028   | 560,162   | 149,538    | 57,010    | 323,636         | 617,172   | 2,339      | 55,851   | 2,501      | 673,023   |
| 1945...  | 13,601    | 91,345    | 519,343    | 53,593    | 532,944         | 144,947   | 442        | 11,206   | 701        | 156,153   |
| Total... | 2,208,925 | 1,639,450 | 10,462,235 | 1,132,129 | 12,671,160      | 2,771,579 | 18,475     | 397,274  | 24,810     | 3,168,953 |

<sup>1/</sup> Figures obtained from the Bureau of Mines Minerals Yearbook. Figures for 1946 to 1949 not separately reported.

TABLE 6. - Sheet, punch, and scrap mica sold or used in Connecticut, 1920-1945<sup>1/</sup>

| Year     | Sheet   |         | Punch     |         | Total           |         | Scrap      |         | Total      |         |
|----------|---------|---------|-----------|---------|-----------------|---------|------------|---------|------------|---------|
|          | Pounds  | Value   | Pounds    | Value   | Sheet and punch | Value   | Short tons | Value   | Short tons | Value   |
| 1920...  | -       | -       | -         | -       | -               | -       | -          | -       | -          | -       |
| 1921...  | -       | -       | -         | -       | -               | -       | -          | -       | -          | -       |
| 1922...  | -       | -       | 4,000     | \$460   | 4,000           | \$460   | 2          | \$44    | 4          | \$504   |
| 1923...  | -       | -       | 500       | 45      | 500             | 45      | 51         | 1,019   | 51         | 1,064   |
| 1924...  | -       | -       | -         | -       | -               | -       | 8          | 160     | 8          | 160     |
| 1925...  | 9,475   | \$3,579 | 4,771     | 236     | 14,246          | 3,815   | 27         | 684     | 34         | 4,499   |
| 1926...  | 7,620   | 553     | -         | -       | 7,620           | 553     | -          | -       | 4          | 553     |
| 1927...  | 320     | 80      | 41,958    | 3,175   | 42,278          | 3,255   | 17         | 301     | 38         | 3,556   |
| 1928...  | 20,177  | 18,159  | 40,709    | 6,106   | 60,886          | 24,265  | 50         | 800     | 80         | 25,065  |
| 1929...  | 46,128  | 37,012  | 47,011    | 5,617   | 93,139          | 24,629  | 119        | 2,724   | 165        | 45,353  |
| 1930...  | 8,015   | 5,366   | 4,700     | 325     | 12,715          | 5,691   | 242        | 3,660   | 248        | 9,351   |
| 1931...  | 29,870  | 19,137  | 84,448    | 2,422   | 114,318         | 21,559  | 296        | 5,344   | 353        | 26,903  |
| 1932...  | 11,279  | 6,958   | 38,641    | 773     | 49,920          | 7,731   | 93         | 1,394   | 118        | 9,125   |
| 1933...  | 15,155  | 8,773   | 17,587    | 894     | 32,542          | 9,667   | 349        | 5,231   | 365        | 14,898  |
| 1934...  | 33,587  | 23,460  | 77,747    | 3,119   | 111,334         | 26,579  | 439        | 7,753   | 494        | 34,332  |
| 1935...  | 95,327  | 46,817  | 169,923   | 5,943   | 265,250         | 52,760  | 620        | 10,171  | 753        | 62,931  |
| 1936...  | 92,952  | 49,900  | 156,232   | 6,750   | 249,148         | 56,650  | 705        | 11,741  | 830        | 68,391  |
| 1937...  | 90,720  | 31,046  | 311,091   | 12,242  | 401,811         | 43,288  | 561        | 8,616   | 762        | 51,904  |
| 1938...  | 50,000  | 26,000  | 124,540   | 5,000   | 174,540         | 31,000  | 800        | 14,400  | 887        | 45,400  |
| 1939...  | 61,036  | 45,404  | 218,472   | 13,768  | 279,508         | 59,172  | 213        | 3,483   | 353        | 62,655  |
| 1940...  | 40,709  | 25,467  | 244,981   | 14,849  | 285,690         | 40,316  | 300        | 4,900   | 443        | 45,216  |
| 1941...  | 95,009  | 118,761 | 157,816   | 11,135  | 252,825         | 129,896 | 201        | 3,983   | 327        | 133,879 |
| 1942...  | 25,106  | 16,570  | 196,377   | 14,231  | 221,483         | 30,801  | 200        | 4,443   | 311        | 35,244  |
| 1943...  | 36,956  | 38,711  | 165,186   | 26,528  | 202,142         | 65,239  | 304        | 6,795   | 405        | 72,034  |
| 1944...  | 50,857  | 137,571 | 26,219    | 9,558   | 77,076          | 147,129 | 593        | 13,798  | 623        | 160,927 |
| 1945...  | 1,009   | 6,879   | 60,823    | 3,246   | 61,832          | 10,125  | 70         | 1,752   | 101        | 11,877  |
| Total... | 821,307 | 666,203 | 2,193,532 | 146,422 | 3,014,839       | 812,625 | 6,260      | 113,196 | 7,757      | 925,821 |

<sup>1/</sup> Figures obtained from the Bureau of Mines Minerals Yearbook. Figures for 1946 to 1949 not separately reported.

TABLE 7. - Production of ground mica in the United States, 1923-49

| Year    | Dry ground |           | Wet ground       |            | Percent of total | Short tons | Value     | Percent of total | Short tons | Value     | Total |
|---------|------------|-----------|------------------|------------|------------------|------------|-----------|------------------|------------|-----------|-------|
|         | Short tons | Value     | Percent of total | Short tons |                  |            |           |                  |            |           |       |
| 1923... | 4,335      | \$188,934 | 67               | 2,102      | 68               | 2,868      | \$250,170 | 33               | 6,437      | \$439,104 |       |
| 1924... | 6,021      | 157,854   | 68               | 2,868      |                  |            |           |                  |            |           |       |
| 1925... | 5,186      | 166,224   | 68               | 2,402      | 66               | 2,490      | 206,370   | 34               | 7,300      | 374,660   |       |
| 1926... | 4,810      | 168,290   | 66               | 2,490      |                  |            |           |                  |            |           |       |
| 1927... | 5,851      | 149,307   | 65               | 3,199      | 71               | 3,317      | 332,511   | 29               | 11,507     | 534,054   |       |
| 1928... | 8,190      | 175,596   | 71               | 3,317      |                  |            |           |                  |            |           |       |
| 1929... | 9,549      | 196,218   | 78               | 2,697      | 84               | 1,575      | 328,332   | 22               | 12,246     | 524,550   |       |
| 1930... | 8,139      | 236,666   | 84               | 1,575      |                  |            |           |                  |            |           |       |
| 1931... | 8,090      | 191,505   | 77               | 2,444      | 78               | 2,452      | 184,126   | 23               | 10,534     | 459,158   |       |
| 1932... | 8,879      | 165,094   | 78               | 2,452      |                  |            |           |                  |            |           |       |
| 1933... | 11,168     | 196,458   | 77               | 3,392      | 80               | 2,723      | 263,503   | 23               | 11,331     | 349,220   |       |
| 1934... | 11,042     | 222,877   | 80               | 2,723      |                  |            |           |                  |            |           |       |
| 1935... | 15,178     | 341,825   | 83               | 3,145      | 81               | 4,785      | 201,148   | 17               | 13,765     | 470,161   |       |
| 1936... | 20,800     | 457,042   | 81               | 4,785      |                  |            |           |                  |            |           |       |
| 1937... | 21,150     | 457,879   | 78               | 6,095      | 73               | 7,329      | 381,933   | 22               | 27,086     | 839,812   |       |
| 1938... | 19,757     | 466,959   | 73               | 7,329      |                  |            |           |                  |            |           |       |
| 1939... | 23,222     | 547,539   | 75               | 7,702      | 74               | 11,505     | 500,698   | 26               | 30,924     | 1,156,333 |       |
| 1940... | 21,809     | 515,930   | 78               | 6,175      |                  |            |           |                  |            |           |       |
| 1941... | 31,914     | 733,559   | 77               | 10,610     | 78               | 11,326     | 798,792   | 23               | 46,979     | 1,653,358 |       |
| 1942... | 36,369     | 805,163   | 77               | 10,610     |                  |            |           |                  |            |           |       |
| 1943... | 40,256     | 1,027,781 | 78               | 11,326     | 89               | 5,690      | 532,562   | 11               | 52,713     | 1,914,709 |       |
| 1944... | 47,023     | 1,382,147 | 89               | 5,690      |                  |            |           |                  |            |           |       |
| 1945... | 43,686     | 1,243,075 | 84               | 8,120      | 87               | 8,205      | 752,894   | 16               | 51,806     | 1,995,969 |       |
| 1946... | 53,908     | 1,582,974 | 87               | 8,205      |                  |            |           |                  |            |           |       |
| 1947... | 55,731     | 1,852,768 | 86               | 8,809      | 86               | 9,148      | 1,114,945 | 14               | 64,540     | 2,516,018 |       |
| 1948... | 55,494     | 2,035,618 | 86               | 9,148      |                  |            |           |                  |            |           |       |
| 1949... | 49,133     | 1,850,400 | 87               | 7,260      | 13               | 56,393     | 1,010,556 | 13               | 56,393     | 2,860,956 |       |
|         |            |           |                  |            |                  |            |           |                  |            |           |       |

1/ Figures obtained from the Bureau of Mines Minerals Yearbook.

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